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CFB GAGETOWN LOW NOx/SOx PROGRAM

TESTS CONDUCTED 1982, 1984 & 1985

REPORT FOR CANMET

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TABLE OF CONTENTS

	PAGE
ABSTRACT	1
SECTION	
1 INTRODUCTION	2
2 TEST OBJECTIVES	3
3 EXISTING FACILITY	4
4 THE STEINMUELLER SYSTEM	14
4.2 LIMESTONE SYSTEMS	24
4.2.1 Copulverizer System for 1982 Tests	
4.2.2 Volcano/Steinmueller Limestone Injection System	
5 TEST PROCEDURE	29
5.1 SAMPLING	
6.0 RESULTS - COMPARISONS AND DISCUSSION	34
6.1 Nitrogen Oxides	34
6.1.1 1982 Baseline Tests	34
6.1.2 November 1984 Tests	34
6.1.3 November/December 1985 Tests	35
6.2 SULPHUR DIOXIDE LEVELS	36
6.2.1 1982 Baseline Tests	36
6.2.2 November 1984 Tests	36
6.2.3 November/December 1985 Tests	37
6.3 COMPARISON OF KEY TEST RESULTS	37
6.4 TEST RESULTS	40
7.0 CONCLUSION	44
8.0 OPERATING PROBLEMS AND RECOMMENDATIONS	45
9.0 APPENDIX	46

GAGETOWN PERFORMANCE TESTS NOVEMBER 1984, NOVEMBER/DECEMBER 1985 AND COMPARISONS WITH 1982 BASELINE TESTS

Abstract

The Canadian Centre for Mineral & Energy Technology (CANMET)- Energy, Mines & Resources Canada, with the participation of the Department of National Defence and the co-operation of Environment Canada, awarded a contract to install and commission two low NOx/SOx, pulverized coal burners. The prime contractor was Volcano Inc. of St. Hyacinthe, Quebec. The burners, designed by Steinmueller of West Germany have been installed in unit no. 2 of the heating plant at Canadian Forces Base Gagetown, New Brunswick.

This report describes performance tests, conducted in March 1982, Nov 1984 & Nov/Dec 1985, as well as an evaluation of the operation of the Steinmueller burners from autumn 1984 to February 1986. G. A. Robb Associates was responsible for coordinating the testing program, calculation of Ca/S ratios and evaluation of the burners in terms of their effect on boiler efficiency and ability to operate satisfactorily. Environment Canada was responsible for monitoring levels of particulate matter, NOx and SOx in the flue gas with and without limestone addition.

The report discusses the results of all three sets of tests. It compares results of the two sets of tests of the Steinmueller burners with baseline tests of the CE burners conducted in 1982 and 1984. The baseline tests provided reference data against which performance of the new burner and limestone injection system were compared. Limestone was copulverized with the coal in a number of tests in 1982 to provide a comparison with limestone injection via the tertiary air ports.

1.0 INTRODUCTION

Emissions of nitrogen and sulphur oxides from coal fired power plants are major contributors to acid rain and other pollution problems. The technology dealt with here is less capital intensive than scrubbers. It is suitable for situations where boiler capacity factors and coal sulphur levels are relatively low. In these situations scrubbers are generally not deemed to be justified.

G. A. Robb Associates, on behalf of EMR, provided overall co-ordination of the testing carried out Mar 26 through Mar 30, 1982, Nov 23 through Nov 28, 1984 and Nov 28 through Dec 3, 1985. Stack emissions were measured by the Pollution Measurement Division of the Air Pollution Control Directorate of Environment Canada. Field support and service was provided by the operating staff of the heating plant. The co-operation of F. Pollitt, plant superintendent in 1982, of B. Wile, present plant superintendent, and the assistance of R. Warman during all three sets of tests is acknowledged. The New Brunswick Research and Productivity Council provided analytical support during the tests. The coal, limestone and ash samples from the Nov 1984 tests were analysed by Cyclone Engineering Sales Ltd. of Edmonton. Other test samples were analysed by CANMET.

G.K. Lee of EMR, the scientific authority directed the entire program. M. M. MacDonald assisted with the 1984 tests.

G. A. Robb, Volcano and G. K. Lee returned to the site in Spring 85 to evaluate operating problems. Excessive carbon carryover has been a problem and a satisfactory solution has not yet been found. Delayed combustion or puffing has also been a problem. The burners were modified with tertiary air deflectors, a larger area coal injector and coal mixing vanes during the summer of 1985. It was not, however,

possible to reduce puffing to a manageable level without impairing the NOx reduction. The carbon carryover level has not yet been reduced to manageable levels. The tertiary air baffles were removed and G. A. Robb returned to the site, with representatives of Environment Canada in February 1986, to determine whether burner puffing and carbon carryover were reduced. The teriary air baffles had directed some of the tertiary air into the reducing zone of the flame.

2.0 TEST OBJECTIVES

The objective of the Nov/84 and Nov/Dec/85 tests was to evaluate the low NOx burner/limestone injection system and determine whether the contract requirements had been met. Baseline tests, conducted in March of 1982, provided a reference which served as a basis for the contract requirements. The March/82 tests were performed with a coal different from the Nov./84 test coal, but the contract allows for variations in coal analysis. Unit 1 was tested with the Nov/84 test coal to develop a second set of baseline data. Solution of the current operating problems is a priority objective of the program.

2.1 CONTRACT REQUIREMENTS

Volcano Inc. with the help of their subcontractor, Steinmuller, was required to achieve the following performance operating at full load on unit 2 without oil support.

- Nitrogen oxide and sulphur oxide emissions should be reduced by 50% or more from baseline levels using the specified coal and Havelock Limestone with a Ca/S mole ratio of not more than 2.5. The NOx target was set at 250 ppm and the SOx target at 950 ppm both corrected to 3% oxygen. The base line levels established by the 1982 tests were 500 ppm NOx and 1900 ppm SO2 (corrected to 3% oxygen

in flue gas).

- The temperature of the flue gas entering the air heater should not exceed 390° C with soot-blowing every four hours.
- No flame impingement on the furnace walls .
- Deposits should be removable by soot-blowing.
- Combustibles should be held to 7% by weight of the flyash (from the mechanical collectors (cyclone collectors)).
- The efficiency should not be less than 82% operating with coal only.

2.1.1 Warranty

The contractor was required to warrant that the equipment will operate as an integral part of the heating plant. Implicit in this is the requirement that the burners perform satisfactorily without undue puffing (delayed combustion), carbon carryover or other indications of unsafe conditions.

3.0 THE EXISTING FACILITY

The Gagetown heating plant consists of 3 - 21 MWT (70 MBTU/hr), CE Lamont controlled circulation, balanced draft, hot water boilers. The installation was built in 1953 by Combustion Engineering, Figure 1, page 6. Each boiler had two CE type RO, front-wall mounted, pulverized coal burners with one directly above the other. Each burner, has a dedicated Raymond Bowl Mill pulverizer. The capacity per burner is 35 million BTU/hr for a total capacity of 70 MBTU/hr (21 MW), Figures 2. A maximum of two boilers operate during winter with one on standby.

It should be noted that a small amount of no. 2 oil is required to maintain flame stability. Oil has been used historically because of coal feed interruptions leading to momentary loss of ignition and subsequent "puffs" of various

intensities. The old flame failure system was unable to trip the boiler in a short enough time. The new flame management system can initiate a trip in less than a second and, if the coal feed is steady, should allow operation at full load without oil support. This oil input was accounted for in analysing the test results.

The Gagetown boilers are much smaller than most pulverized coal boilers. There is less mutual support among burners than with larger boilers and the furnace temperature is lower. This together with the fact that the old installation did not have a modern burner management system accounts for continuous use of oil at full load.

Each of the CFB Gagetown units has an air preheater bypass to limit metal temperatures and avoid corrosion of the tubes. These are normally closed at full load but are opened at lower loads.

Combustion control systems are by Bailey with automatic fuel flow/air flow proportioning and zirconium oxide fuel-cell-type oxygen analysers at the boiler outlet. There is provision for adding furnace gas to the primary air, prior to the pulverizers, to increase temperature. Furnace outlet and airpreheater outlet gas temperatures are recorded as are air preheater inlet and outlet air temperatures. The air preheater outlet temperature is not necessarily the combustion air temperature because of the air preheater bypass.

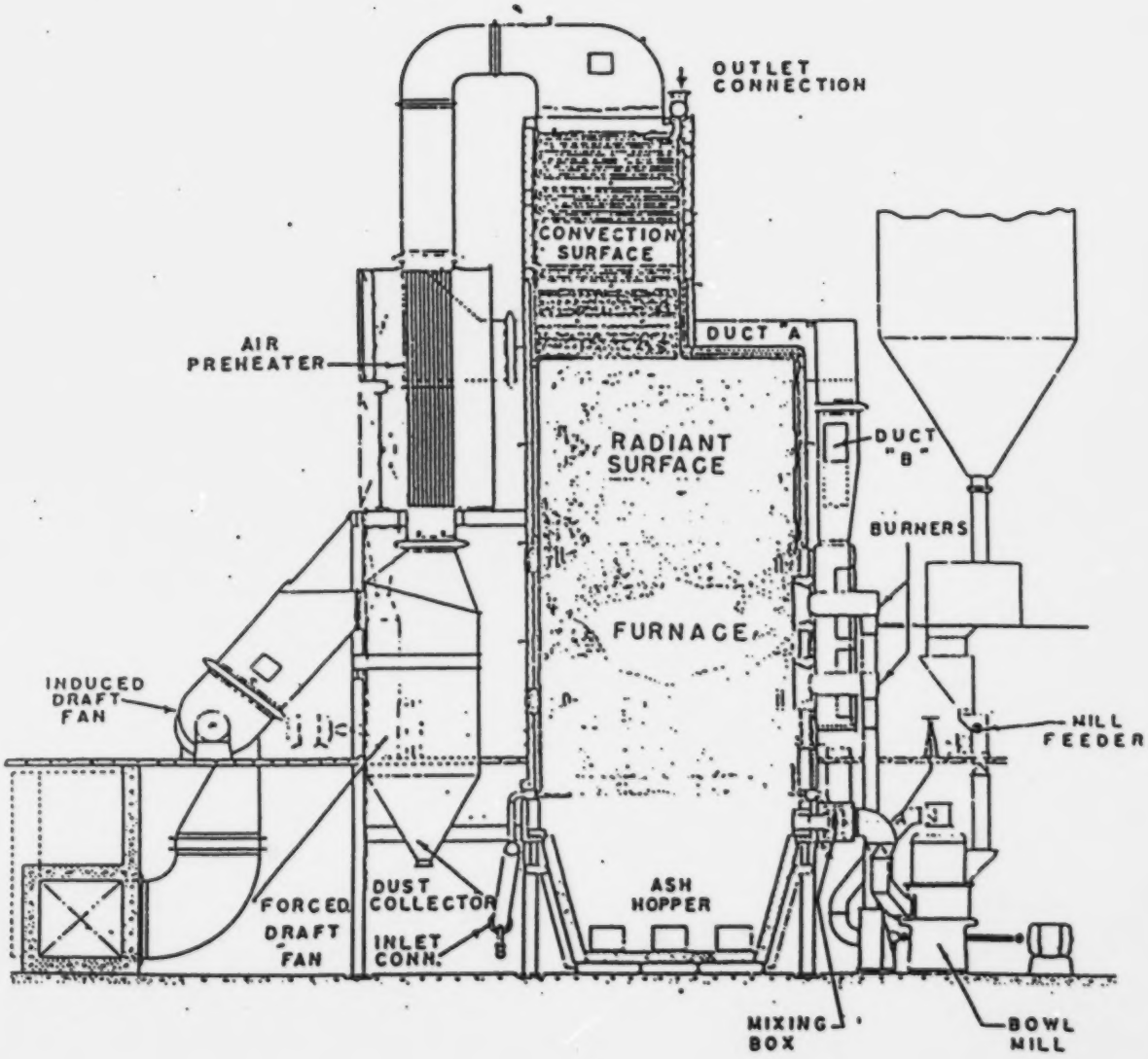


Figure 1 Section View of CE-Lamont Hot Water Boiler

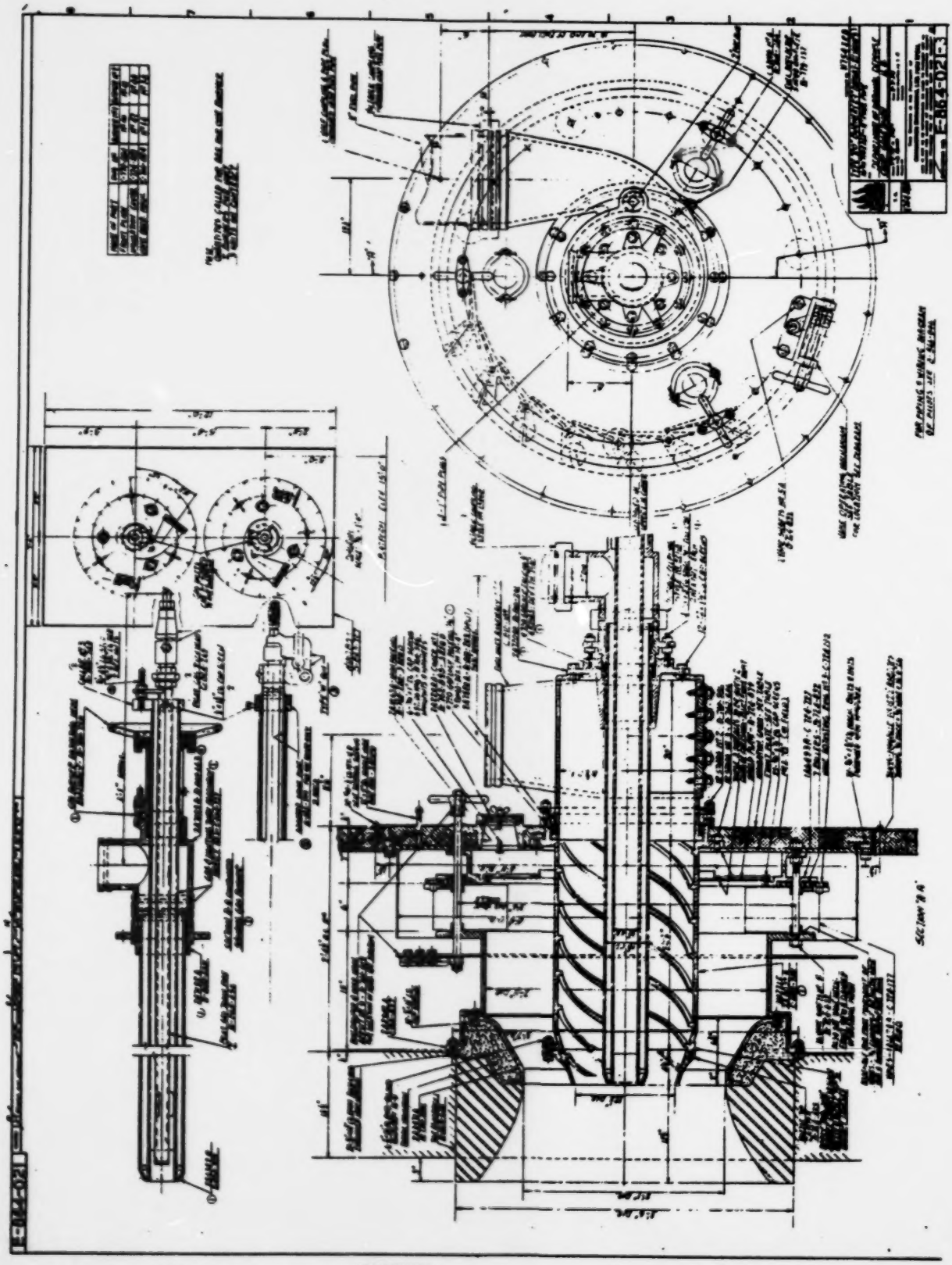


Figure 2 BURNER Source: Combustion Engineering

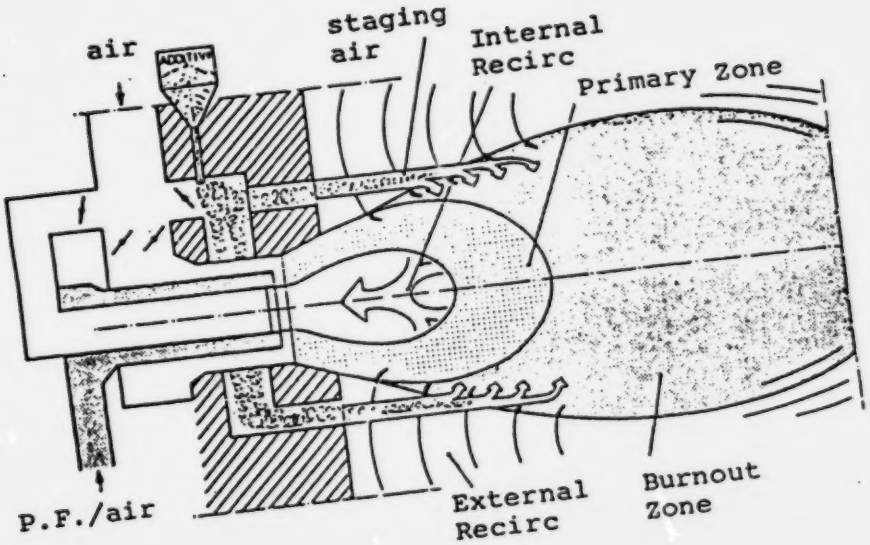


Figure 3 SM-burner with additive injection

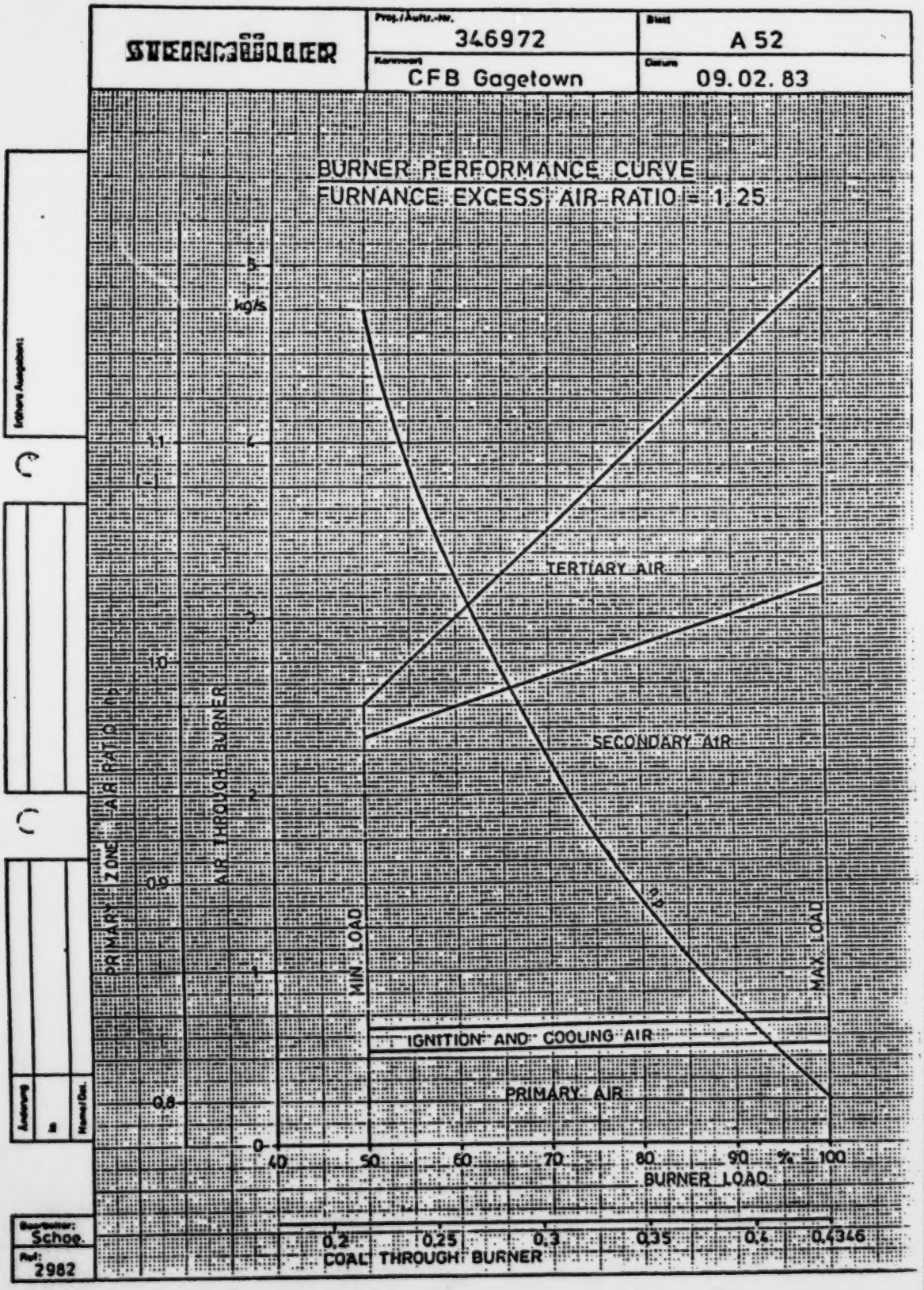
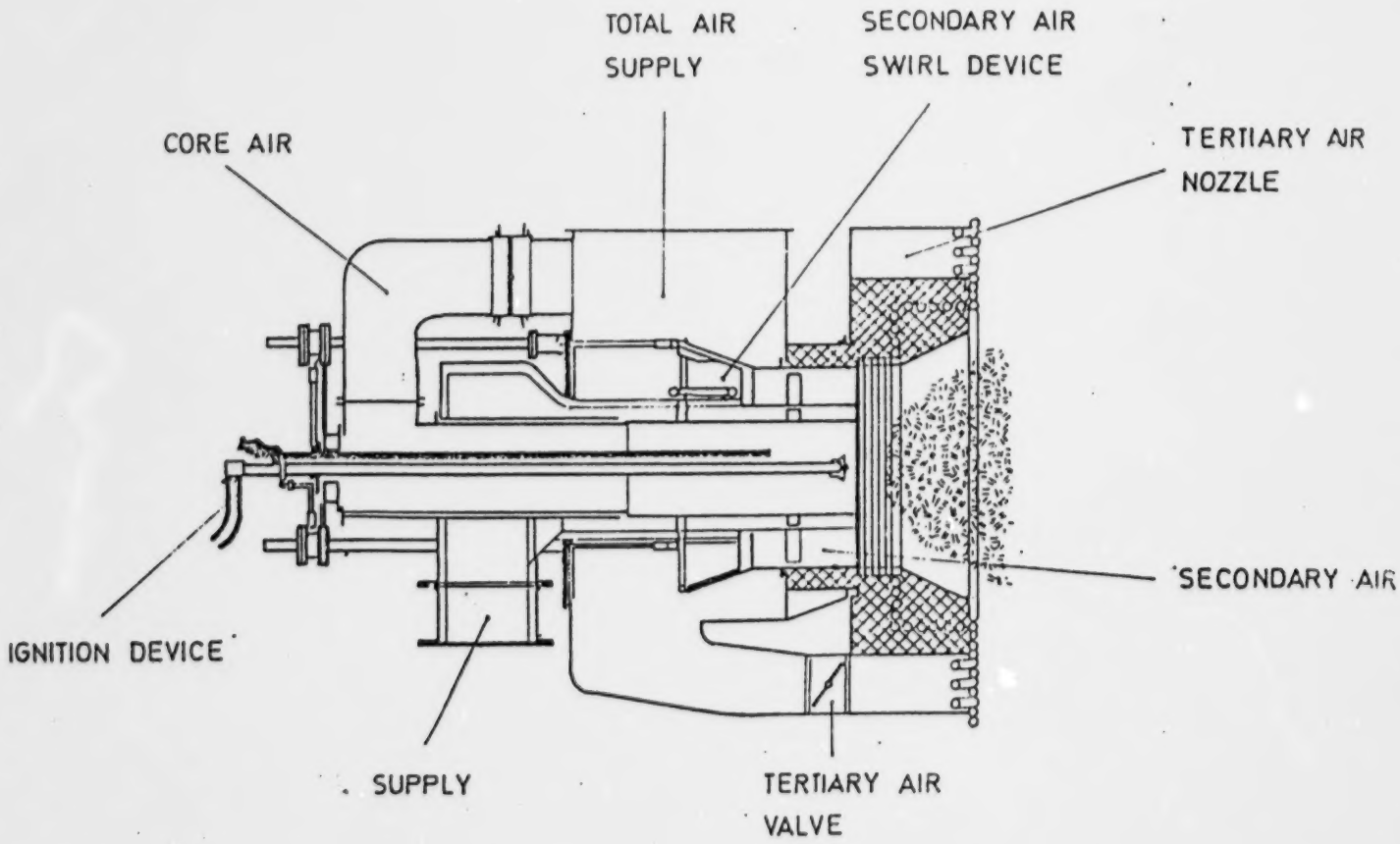


Figure 4 Burner Air Flows

Figure 5 STAGED MIXING BURNER

(SM - BURNER)



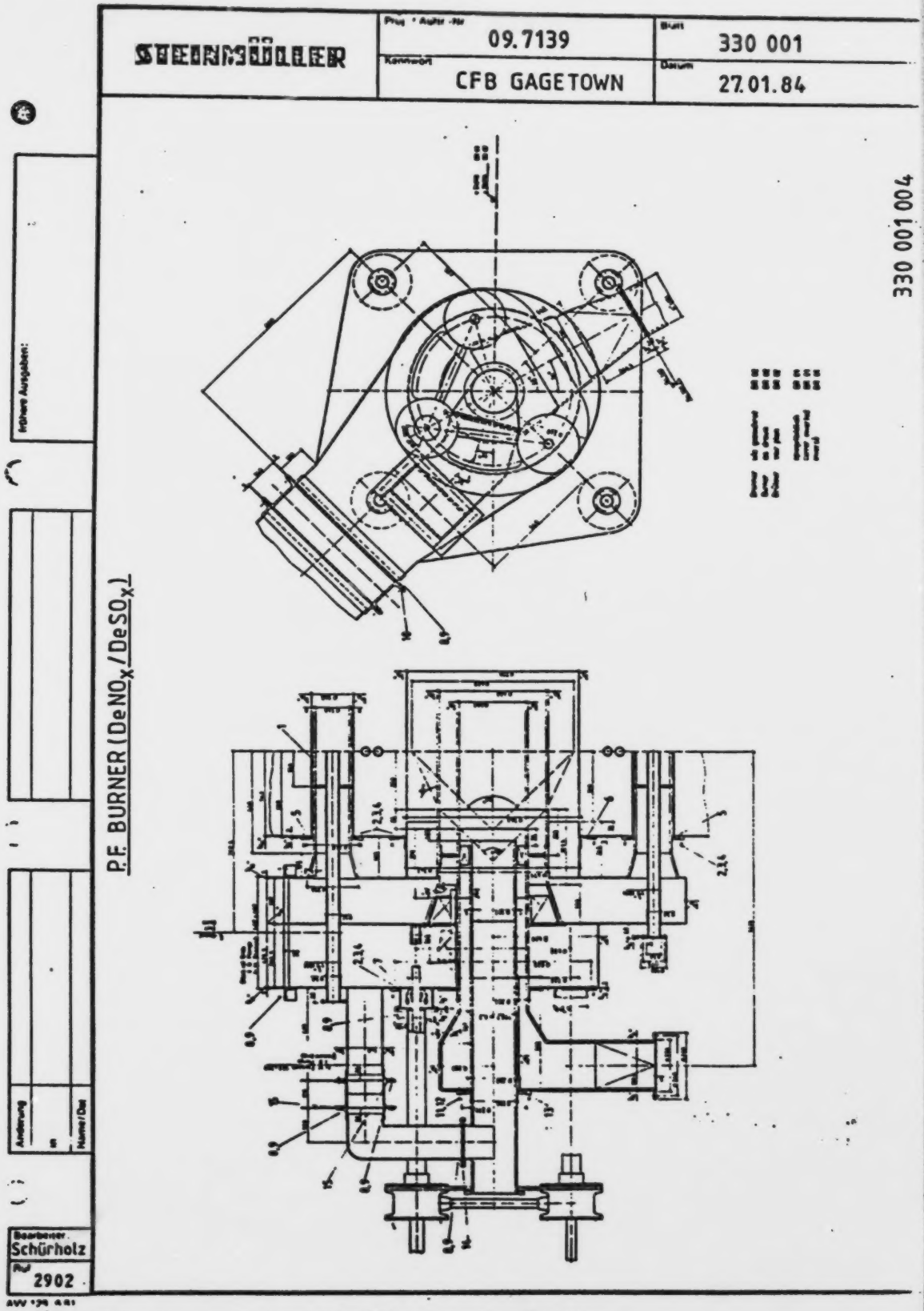
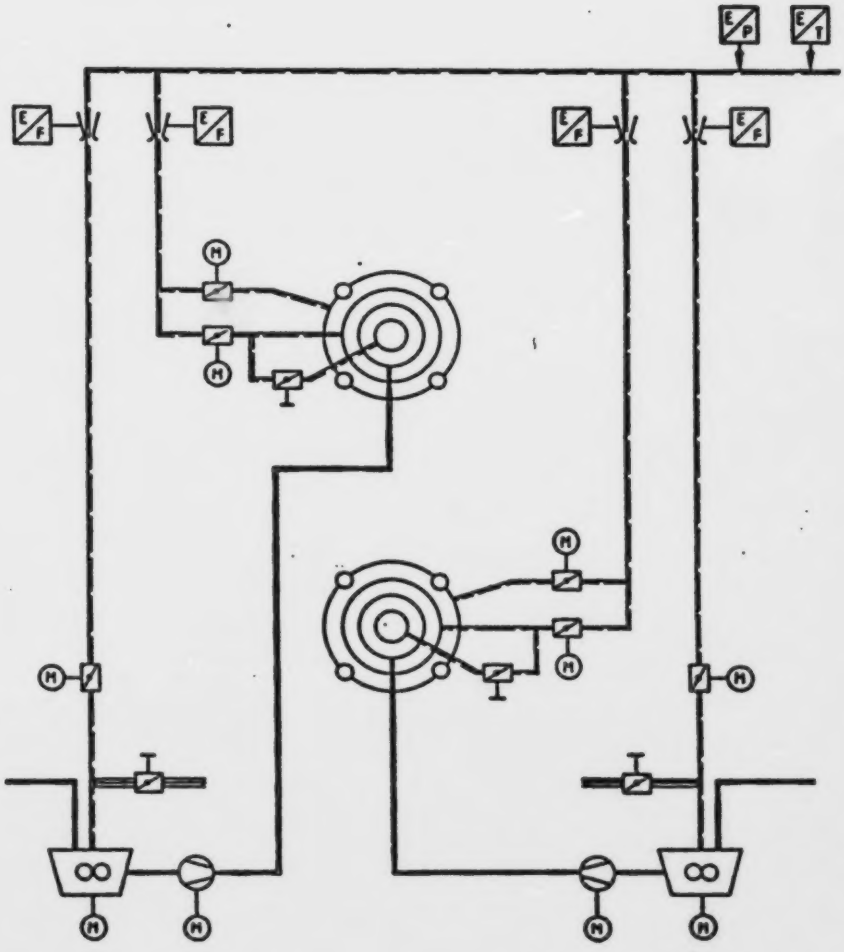


Figure 6 Low NOx/SOx Burner Design

STEINMÜLLER	Proj. / Auftr.-Nr. 09.7139	Plan S 02 001
	Kennwort CFB GAGETOWN	Datum 30.01.84

Figure 8 P & I. DIAGRAM COAL - AIR



Bearbeiter: Schürholz
Plot: 2902

Figure 9 Burner Control and Flame Protection Panel

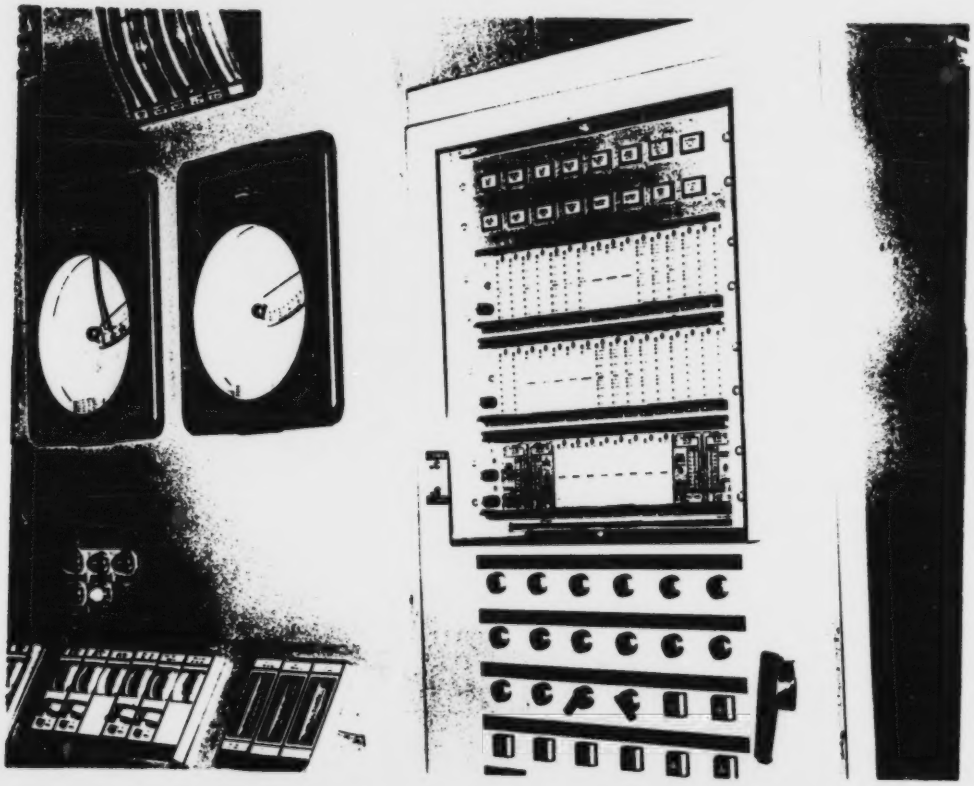


Figure 7 SM Burner showing Limestone Injection Points

4.0 THE STEINMUELLER SYSTEM

4.1 LOW NOx BURNERS

Hot water generator no. 2 is now equipped with two, combined P. F./oil fired, stage mixing, low nitrogen oxide burners shown in figure 3, page 8. A limestone (or other additive) injection system has been installed to reduces sulphur oxide emissions. The new burners replace two Combustion Engineering burners which were installed as original equipment.

The first combustion stage, near the burner tip, is a reducing zone. The fuel should ignite but less NOx is formed because the air supply to that zone is sub-stoichiometric. The oxygen reacts preferentially with carbon and hydrogen leaving no surplus to react with fuel nitrogen to form nitrogen oxides.

Combustion is completed in the second stage, a lower temperature zone, where less NOx is formed than would be formed in a high temperature zone with excess air.

With copulverization of the limestone with the coal, the limestone is introduced to the furnace through a high temperature zone. This leads to "dead burning" of the limestone which causes surface pores in limestone particles to be covered with fused material, thereby reducing surface area and the probability of reaction with sulphur. The Steinmueller system introduces limestone or other additive with the tertiary air so it bypasses the high temperature zone. There is little deadburning and a higher probability of reaction with sulphur.

The pulverized fuel burners are designed for a turn-down range of 1:2, ie. 50% minimum or 100% maximum burner load. This should allow operation at 25% hot water generator load

as a minimum and 100% HW generator load as a maximum.

A performance curve indicating the flow rates at various loads for:

- coal
- primary air
- secondary air
- tertiary (staging air)

  is shown in figure 4, page 9.

Fuel

The burner was designed for a bituminous coal with the following analysis.

Net calorific value ..... 28.78 MJ/kg
Moisture..... 10 %
Ash ..... 9 %
Volatiles ..... 36.7 %
Specific air demand ..... 9.2 kg/kg

According to, Annex 1 and Annex 2 to Appendix "A" of the contract, the coal specification and permissible design variation in coal analysis are as follows.

Ultimate analysis, % by weight

	SPEC.	RANGE	
		From	To
Carbon	75.2	72	79
Hydrogen	4.8	4.5	5
Sulphur	3	not to be more than 3	
Nitrogen	1.4	not to be more than 1.4	
Ash	10.0	8	12
Oxygen	5.6(by dif.)	range by difference.	

Proximate Analysis

	As received.	Dry
Moisture	10, range 8 to 12,	0.0
Volatile matter	30, range 29 to 33,	33
Fixed carbon	51, range 48 to 53,	57
Ash	9, range 8 to 12,	10

Higher heating value dry spec. 33.3 MJ/kg not less than 30
Hardgrove grindability index spec. 59, not less than 55

The complete specification from the contract is in the appendix of this report of this report.

4.1.1 Burners

Number 2
Design..... Steinmuller
Type ..... Staged mixing
Max pulverized coal flow rate per burner.. 0.434 kg/sec
Max admissible thermal capacity per burner..... 12.4 MW

4.1.2 Operation of Burners

The pulverized coal/air mixture is withdrawn from the pulverizer by the mill exhauster which is a straight radial blade centrifugal fan. There is provision for recirculation of air/coal mixture from the exhauster outlet back to the pulverizer. There is also provision for temperature control by adding combustion products from the furnace to the primary air before it enters the pulverizer.

The coal/air mixture (and possibly some combustion gases) is delivered to the burner inlet via a round pipe connected to a symmetrical divergent inlet. The velocity reduction is designed to break up any agglomeration of the fuel.

The burner gun assembly, shown in figures 5, 6 and 7, consists of inner and outer pipes passing through the windbox to the burner throat. The coal/air mixture passes through the annulus formed by the inner and outer burner gun pipes. The core pipe, around which the coal flows, accommodates the oil gun.

The coal burner gun is surrounded by the burner mantle or secondary air ring. This consists of a wide cylindrical tube and the conical air inlet in which the swirl vane assembly is installed. This assembly is comprised of a number of vanes welded between an inner guide ring and a conical wall ring which fits into the corresponding part of the windbox.

The swirl vanes can be adjusted axially by three actuating rods synchronized by gearing. When the swirler moves away from its conical housing, an annular gap is left around it through which a portion of the secondary air can enter the cylindrical shell without swirl. This reduces the swirl effect and hence the swirl angle. This in turn influences the flame configuration.

The swirler position is adjusted by observation of the flame. According to Steinmuller, a pronounced swirl produces a short, broad flame and a slight swirl produces a longer, tninner flame.

The swirl remains unchanged over the full range of operation. Primary, secondary and tertiary air are adjusted to suit the load.

The staging (tertiary) air system consists of a windbox and four staging air nozzles concentric with the burner axis. The nozzles for desulphurization additive injection are centrally arranged in the staging air pipes.

The secondary and tertiary air are admitted to each burner via a separate duct which is split at the entrance to the windbox.

The control circuit for the burner is shown in Figure 8 and a picture of the control panel is shown in Figure 9.

4.1.3 NOx Reduction

The swirl or vortex action sets up a pressure gradient which, according to Steinmuller, causes an inner recirculation of hot flue gases to the burner tip to ensure ignition and stable combustion at the tip. The high temperature primary combustion zone near the burner throat is substoichiometric so the available oxygen combines with carbon and hydrogen in preference to less reactive nitrogen.

The geometry of the throat region together with swirl, secondary air quantity and velocity, the coal/primary air ratio and the velocity of the coal/air/gas mixture leaving the annulus at the burner tip are all important in achieving good ignition with low NOx formation.

4.1.4 Secondary Combustion Zone

Combustion is completed in a secondary combustion zone while there is excess air in the secondary zone, the lower temperature reduces NOx formation. There is a separate damper device for tertiary air.

4.1.4 Changes following 1984 Tests

At the time of the November 1984 tests, the shape of the burner throat as installed was not according to design. Best operation in terms of flame stability was achieved with maximum swirl. When the throat shape was corrected in early 1985, the Steimueller operator returned and best operation was achieved with less than maximum swirl.

During the summer of 1985, the diameter of the core pipe was reduced to reduce the injection velocity of the coal in an attempt to improve ignition and reduce carbon carryover by providing more residence time in the hot zone. Fixed swirle vanes were also added in the coal annulus near the tip in an attempt to improve mixing at the tip and thus improve ignition and reduce carbon carryover. A further change, aimed at reducing carbon carryover, was the addition of vanes to the tertiary air ports to direct the tertiary air so it would enter the flame closer to the burner tip.

The additive , being injected through the tertiary air ports, does not pass through the high temperature zone, so that sintering of the additive can be avoided. Due to high turbulence around the flame, the mixing of the additive with the flue is optimum.

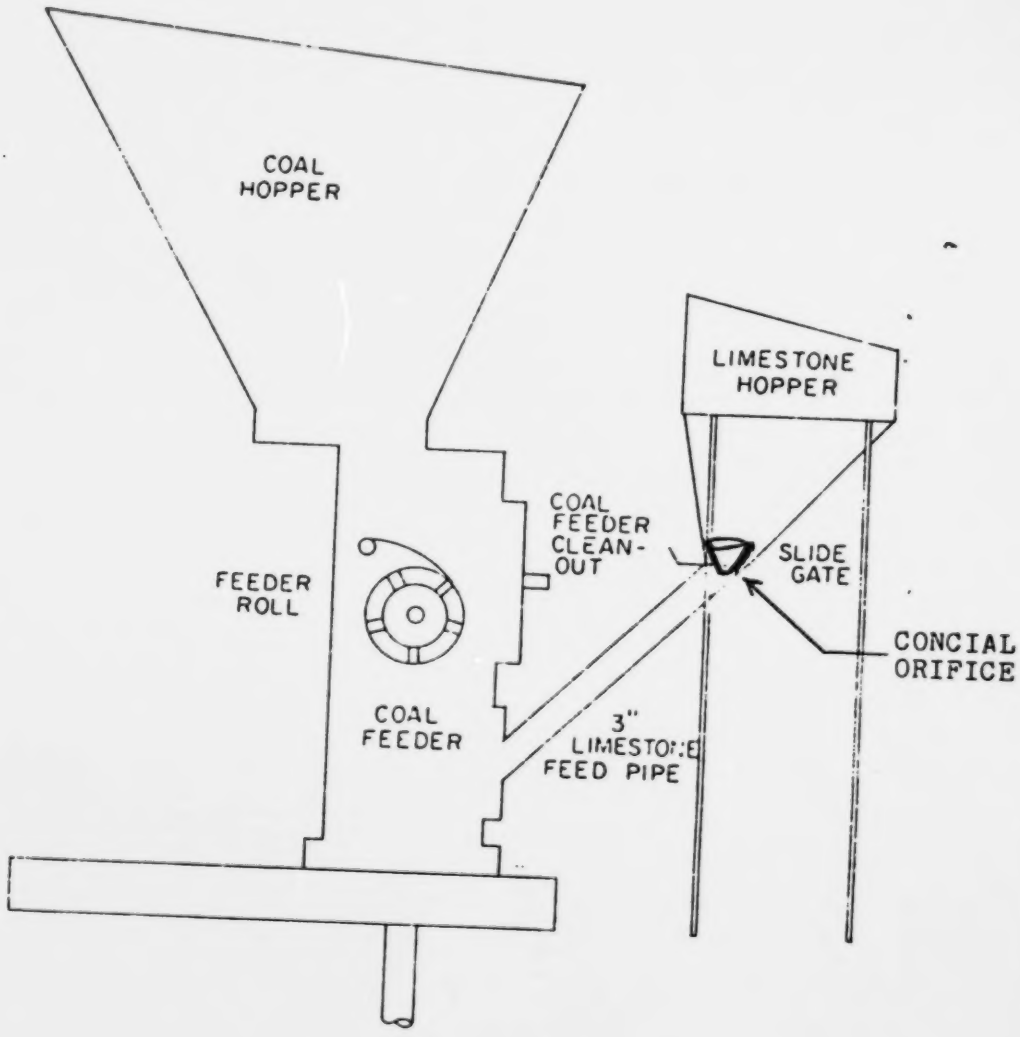
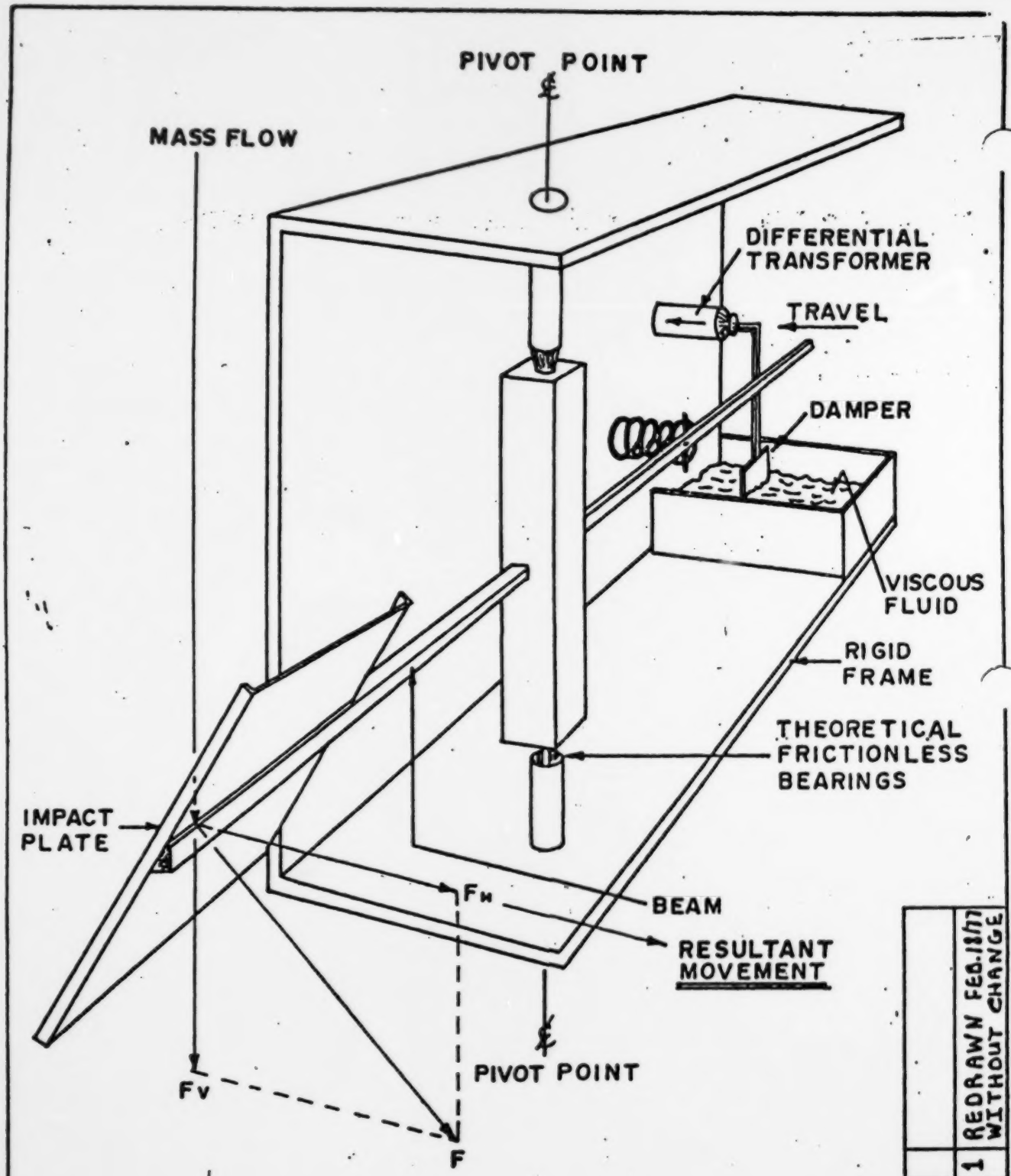


Figure 10

BASELINE TEST LIMESTONE INJECTION SYSTEM

Source:
F.W. Pollitt



REVISIONS		
	1	REDRAWN FEB. 18/77 WITHOUT CHANGE

Milltronics LIMITED PETERBOROUGH CANADA

Figure 11
THEORETICAL MODEL
SANKYO IMPACT LINE
FLOWMETER

DRAWN FEB 18 77 RUSS TYLER	JOB NO.	
CHECKED RDC Feb. 18/77	20A894	REV 1
APPROVED [illegible] Feb 18/77	CONT ON SH – SH 1	

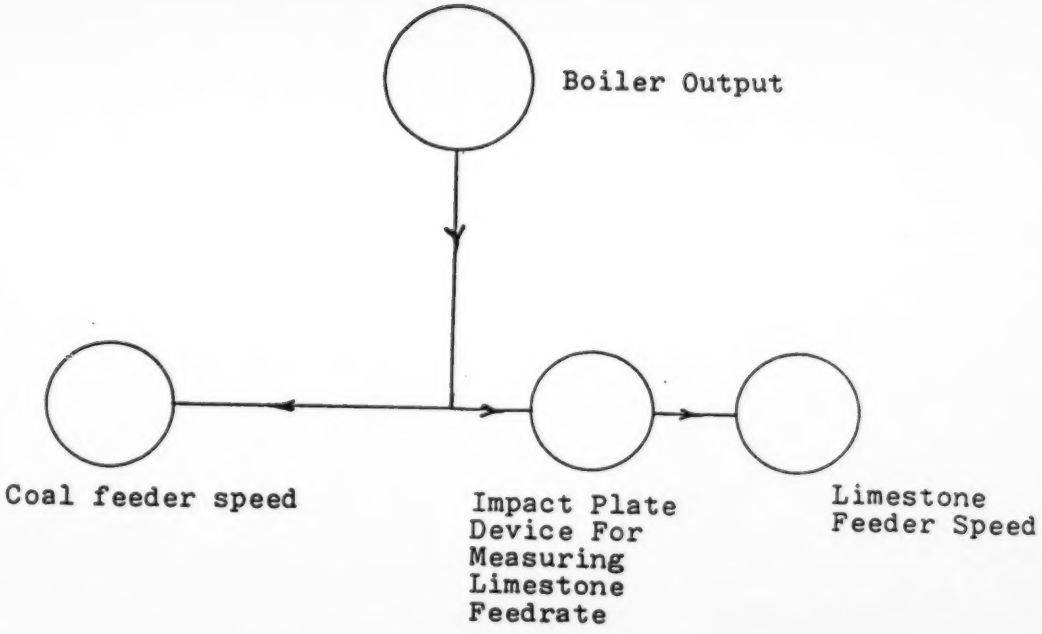


Figure 12

Boiler input = Boiler Output/ Boiler Efficiency

Limestone Feedrate Adjusted by Signal to Coal Feeder Speed To Maintain Ca/S ratio

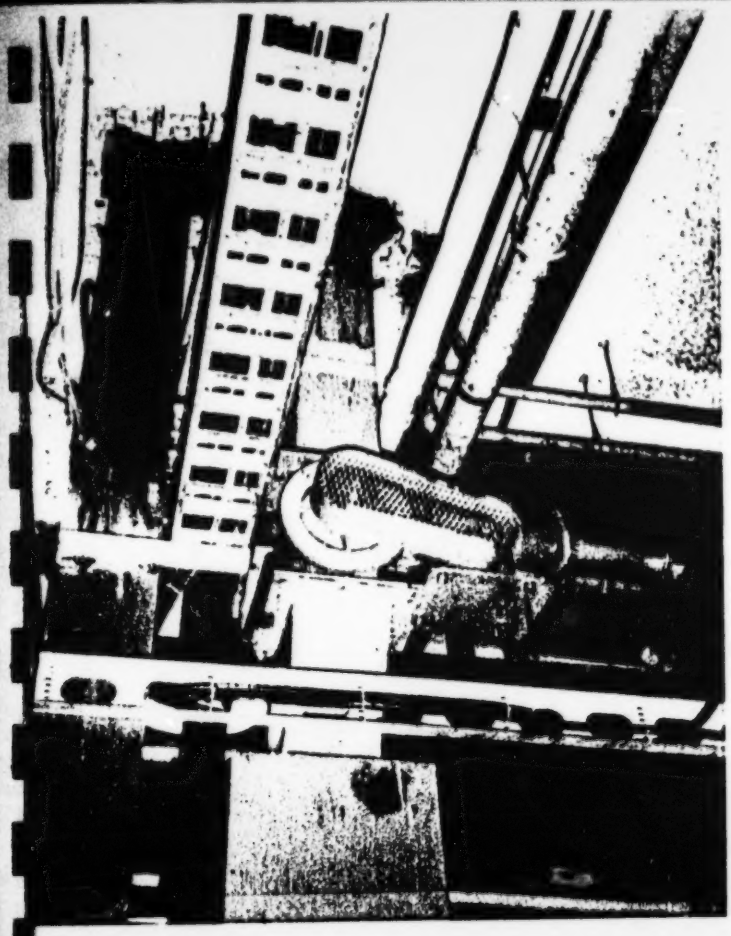


Figure 13

The rotary valve in the duct supplying the impingement plate limestone meter

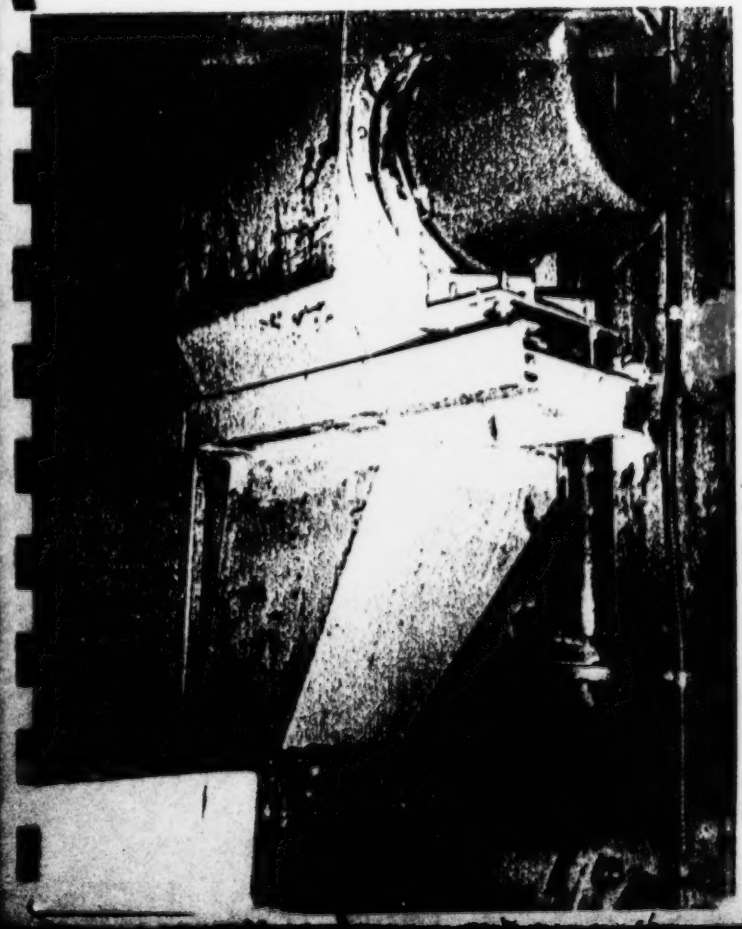


Figure 14

The impingement plate limestone meter and the point at whioh limestone is introduced to the pneumatic conveying system leading to the tertiary air ports of the staged burners

4.2 LIMESTONE SYSTEMS

4.2.1 Copulverizer System for 1982 tests

The system for copulverizing limestone coal, shown in figure 10, was designed by F. W. Pollit, who was heating plant superintendent in 1982. It consisted of a small hopper, a conical orifice and a duct leading to an existing opening just below the rotary coal feeder to each pulverizer.

Granular limestone in bags was piled near the pulverizers and fed to the hopper manually. The orifice was calibrated during a preliminary run. The number of bags per hour provided a check on the limestone feedrate.

During the trial runs pieces of paper and refuse in the limestone plugged the orifice from time to time. This problem was solved by using a coarse wire mesh on the top of the hopper to screen the granular limestone.

The low cost temporary system proved to be satisfactory for developing a basis for comparing the results of copulverization with those with injection of lime dust via the tertiary air ports.

4.2.2Volcano/Steinmueller Limestone Injection System

The limestone used for this system was supplied by Havelock Lime following screening, pulverizing and air classification. It is delivered in tank trucks each carrying 30 tonnes and handled pneumatically. It is stored in a 100 cubic meter cylindrical bin behind boiler no. 2.

The material is marketted as limestone dust with the following sieve analysis.

Screen size	Wt%
+100 mesh	2.7
-100+200	4.7
-200+230	3.1
-230+325	7.3
-325 mesh	79.1
Total	100%

The limestone is fluidized at the bottom of the bin travels horizontally and drops into a vertical duct. It then passes through a rotary feeder, over an impingement plate and into a horizontal venturi through which it is fed to the pneumatic conveying system piping, which supplies each burners. The impact plate, Figure 11, senses limestone flow and a control system linked to the coal feeder, which in turn is linked to boiler output, maintains a preset ratio of limestone flow to coal flow. Assuming constant sulphur level in the coal, this controls the Ca/S ratio, as shown in Figure 12.

Experience has demonstrated that the speed of the rotary valve cannot be used as a measure of limestone flow, because limestone either packs in the sectors and some remains there or some nonuniformity of flow exists in the vertical duct.

For a given limestone flow the valve speed increases which suggests that some of the space in the sectors remains filled with packed limestone. A control of the level of material in the vertical duct would probably help as would automation of the valves at the bottom of the bin and the top of the vertical duct. The impact plate control system maintains a reasonably uniform limestone flow providing the

vacuum under it does not exceed two or three inches of water. The development of excessive vacuum under the impact plate impairs its accuracy.

For purposes of these tests, a manual vacuum breaker (a pipe nipple with a gate valve) was used to limit the vacuum. A second rotary valve, to isolate the space under the impact plate from the venturi which causes the vacuum, has been proposed.

The control panel indicates limestone flow rate as a % of 1200 Kg/hr. As well, there is an integrator which allows determination of the flow rate over a period of time.

The impact plate meter was calibrated by the supplier with the space under the plate at atmospheric pressure. The calibration was checked for the Nov 84 tests and again for the Nov/Dec 85 tests. In both cases a barrel was used. In 1984 a small scale was used to weigh a part of the barrel of limestone. In 1985, a large scale was rented and the entire barrel was weighed at one time. The checks indicated an accuracy within 10%. Because the calibration and the checks were at atmospheric pressure under the impact plate, operation with minimum vacuum under the plate is important.

The bin was filled in autumn 1984 and easily fluidized in later 1984. There was no evidence of caking due to moisture absorption.

After entering the venturi below the impact plate, the limestone dust is conveyed pneumatically to a distributor in front of the boiler from which a separate tube conveys it to each tertiary air port.

Photographs of the additive injection system are shown in Figures 13 and 14.

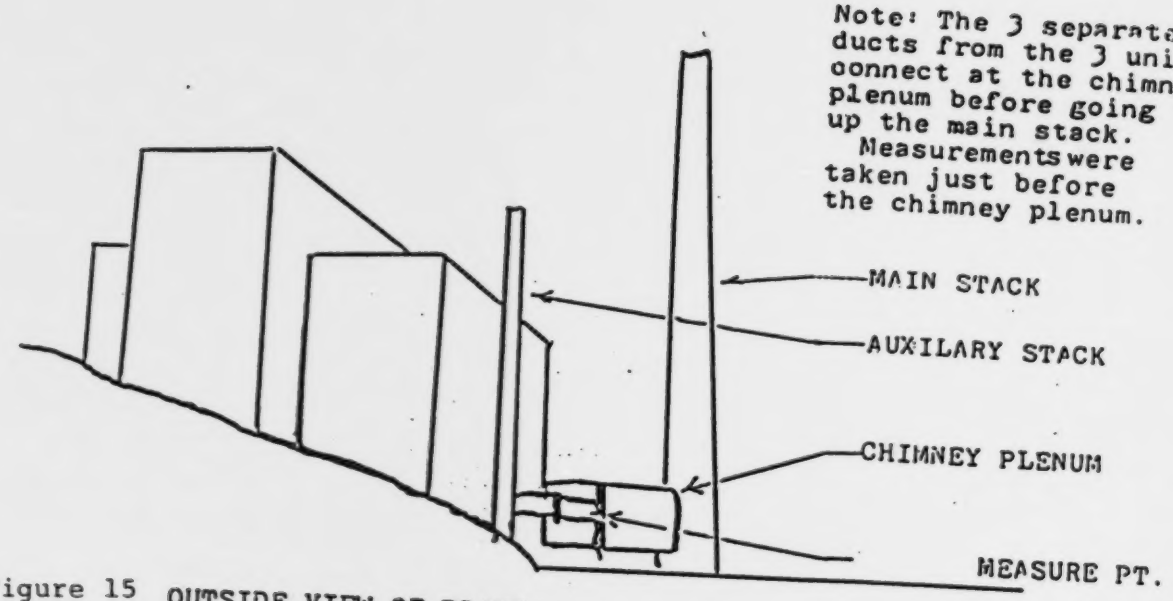

Note: The 3 separate ducts from the 3 units connect at the chimney plenum before going up the main stack. Measurements were taken just before the chimney plenum.
MAIN STACK
AUXILARY STACK
CHIMNEY PLENUM
MEASURE PT.

Figure 15 OUTSIDE VIEW OF PLANT AND ENVIRONMENT CANADA MEASUREMENT POINT

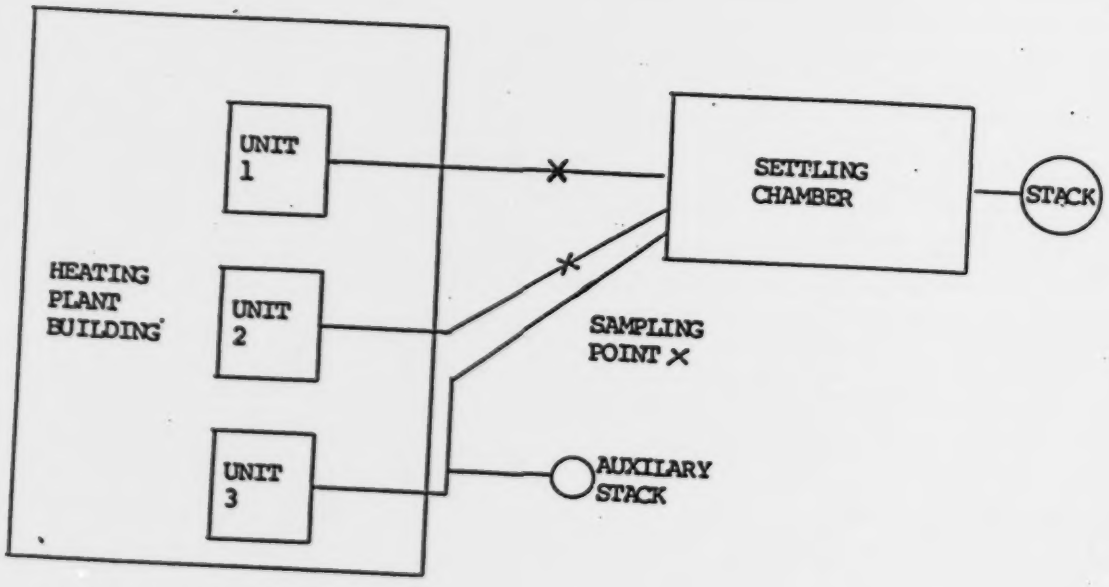


Figure 16 PLAN VIEW OF ENVIRONMENT CANADA MEASUREMENT POINT

5 TEST PROCEDURE

While the contract is based on full load performace, weather conditions limited output during the tests. Heat cannot be generated more rapidly than it can be absorbed by the hot water system. Doors of large buildings were left open in some cases to increase load, but nevertheless, it was necessary to run many of the planned full load tests at less than full load.

Environment Canada measurements were taken at a point between the Pratt Daniel fly ash cyclone collectors and the settling chamber before the stack, Figures 15 and 16.

Nitrogen oxide, sulphur dioxide, oxygen, and carbon monoxide were monitored continuously. For the November 84 and November/December 1985 tests, NOx and SO2 measurements were cross checked by EPS-1-AP-77-3 and EPS-1-AP-77-3 Standard reference methods which involve the analysis of samples collected in bags. The continuous method is far more useful in evaluating the effects of changes in furnace conditions.

Environment Canada measured flue gas flow rate and particulates. The flow rate measurement allowed them to state emission levels in mg/MJ of fuel as well as in ppm corrected to 3% oxygen.

The contract is based on full load tests with limestone injection for comparison with target levels in terms of ppm at 3% oxygen. In addition to the full load tests with limestone injection, full load tests were conducted without limestone and half load tests were conducted with and without limestone.

5.1 SAMPLING

The methods used by Environment Canada are described in more detail in a separate report written by the test team from that organization. The following outline is based in part, on material provided by them.

5.1.1 Continuous Methods

The gas samples for the continuous monitors were extracted from a 4 inch port located upstream of the common settling chamber, downstream of the Pratt Daniel mechanical collectors in a section of duct carrying combustion products from a single boiler combined with a significant amount of inflitrated air. Because of the infiltration the % oxygen data obtained by environment Canada was not used for boiler efficiency determination. As well, the point of measurement is a considerable distance from the boilers so radiation losses from the duct would be reflected by the temperature. There is more infiltration in the case of generator no 3 because of a connection to an auxiliary stack.

Following conditioning of the sample gas to remove particulates and moisture, the cooled, dried gas is then pumped to the continuous monitors for NOx, SO_2, CO and O_2 analysis. The monitors are described in the Environment Canada Report.

The system was calibrated several times daily. The calibration gases were injected immediately after the sample probe so the whole system is calibrated. All concentration data and temperature data were recorded on chart recorders.

5.1.2 Manual Sampling

Manual stack sampling methods were applied for determination of particulate and arsenic emissions and the characterization of sulphates and combustibles. The flue gas samples were collected from 5 ports using isokinetic sampling. These methods also provided the flue gas volumetric flow rate required for determination of NOx and SO_2 mass emission rates. More detail about this will be found in the Environment Canada Report.

5.2 BOILER EFFICIENCY AND Ca/S RATIO DETERMINATION

These two subjects are dealt with together because the coal input estimate used to estimate the Ca/S ratio is determined by using boiler efficiency. There is no direct measurement of coal input. There is too much variation in void fraction in the sectors in the rotary coal feeder for the RPM of it to be used as a measure of coal flow.

The boiler efficiency was determined by the heat loss method. Percent oxygen and temperature were measured at the air preheater outlet. The temperature of the air to the forced draft fan was also measured. These data together with the ultimate analysis of the coal were used with a microcomputer program based on the ASME PTC 4.1 Power Test Code for Steam Generating units to calculate the boiler efficiency. Teledyne portable oxygen analysers and an R. A. B. Dedesco portable oxygen and CO analyser were used to measure % oxygen on a dry basis at the airpreheater outlet. The % oxygen at the boiler outlet is measured by a Bailey fuel cell type analyser on a wet basis. The relationship between the dry basis measurement at the airpreheater outlet and the recorded wet basis measurement at the boiler outlet

was determined. By applying the adjustment to the % oxygen recorder on the boiler operating panel, the equivalent of continuous monitoring of the % oxygen on a dry basis at the boiler outlet was achieved. For the 1982 and 1984 tests the dry basis figure was used with a computer program based on the dry basis % oxygen. By 1985, G. A. Robb Associates had developed a better program which will accomodate % oxygen on either a wet or dry basis. For the 1985 tests it was determined that there was no airpreheater leakage by comparing the boiler outlet % oxygen with the airpreheater outlet % oxygen taking acount of the fact that one was dry basis and the other wet basis. The panel recorder reading was then used directly.

The output of the hot water generator in MW is recorded and these recorders were checked by Bailey before the tests. Input was calculated by dividing output by boiler efficiency. Available data on % by weight of sulphur in the coal was then used to estimate the moles of calcium per mole of sulphur (the Ca/S ratio).

The foregoing is the most practical approach given that there is no direct measurement of coal input. The actual Ca/S ratio cannot be determined until after the results of the analysis of the coal actually used during the test is obtained. The tests were run for a range of Ca/S estimates to ensure that the result for the target Ca/S ratio could be obtained from a curve of SO_2 vs Ca/S ratio. Another solution was to adjust to limestone feedrate until the SO_2 emmissions matched the contract requirements. The Ca/S ratio was estimated later and compared with the 2.5 target.

A further complication was introduced by the fact that for both the 1984 and the 1985 tests (particularly the 1985 tests) the % sulphur by weight in the coal proved to be less

than the target 3%. A lower % reduction in SO_2 is to be expected where the % sulphur in the coal is less than 3%.

In addition to the tests on unit no 2 with the Steinmueller burners, additional baseline tests were performed on unit 1. During the 1982 tests there was a failure in boiler no 2 so baseline testing was changed to boiler no 3. This, changes in coal and the importance of adequate basseline data led to the decision to obtain the additional baseline data.

For each test, coal samples were taken every 30 minutes from the inlet and outlet of alternate pulverizers. Limestone samples were taken periodically through the tests. The hoppers under the cyclone collectors were emptied before each test. After each test a fly ash sample was taken from the hopper. Bottom ash samples were also taken. The samples were stored in plastic bags or jars.

6 RESULTS - COMPARISONS AND DISCUSSION

Tables 1 to 6 inclusive summarize the results of the baseline and low NOx/SOx burner tests.

6.1 NITROGEN OXIDES

6.1.1 1982 Baseline tests

The NOx level range for the 1982 Baseline tests at full load (approximately 19 MW) was 480 ppm to 750 ppm, corrected to 3% oxygen. There were 7 full load tests lasting from 2 to 3 hours each. The average was 604 ppm and the standard deviation 104 ppm.

At half load the NOx range was 300 ppm to 450 corrected to 3 % oxygen. The average was 395 and the standard deviation 53. There were 4 half load tests lasting from 2 to 3 hours each.

The effect of limestone addition on the NOx levels at half load was minimal. At full load, there was an apparent increase in NOx concentration of approximately 20%.

6.1.2 November 1984 Tests

The level of NOx for the November 1984 tests ranged from 211 ppm to 254 ppm adjusted to 3% oxygen. All the November 1984 tests were full load tests. The average for the 4 tests was 231 and the standard deviation was 22. For contract purposes a representative baseline NOx level of 500 ppm was assumed. (The average was 604 but conditions were varied.) For the one supplementary baseline test on boiler no.1 in November 1984 the NOx level was 567 ppm.

The reduction compared with the baseline/contract level was

269 ppm or 53.8%. The reduction compared with the March 1982 average was 376 ppm or 62%. Compared with the November 1984 supplementary baseline test on November 1984 on boiler no.1, the reduction is 336 ppm or 59%. These results meet the contract specifictions, which called for a 50% reduction. The contract target was 250 ppm. Unfortunately the carbon carry over was excessive. To satisfy the contract requirement the NOx reduction was to have been achieved without excessive carbon carry over. There is a trade-off between low NOx and good combustion because of the relatively low temperature in the burnout zone (the second stage of the 2 stage combustion system).

6.1.3 November/December 1985 Tests

These NOx levels reflect the burner changes aimed at reducing puffing and carbon carry over. Some adjusting took place during the tests so levels for 16, fifteen minute periods were tabulated during each of the two days. Averages were tabulated for 3 tests of 1 to 1.5 hours duration each of the 2 days.

On December 2 the average was 472.2 ppm NOx and the standard deviation 5.14 for the 16 fifteen minute periods.

On December 3 the average was 338 ppm NOx and the standard deviation 34.

The reduction for Dec 3 compared with the contact target is 32%. Compared with the 1982 average it is 44 % for Dec 2.

The reduction for Dec 2 compared with the target was only 6% Compared with the 1982 average it was 22%.

Clearly the changes to improve carbon burnout made between

the November 1984 tests and the December 1985 tests impaired the NOx reduction capability of the burner.

6.2 SULPHUR DIOXIDE LEVELS

6.2.1 Baseline Tests 1982

The full load SO2 levels without limestone addition ranged from 1830 to 1970 corrected to 3% oxygen. There were 4 tests each lasting between 2 and 3 hours. The average was 1905 and the standard deviation 50.

At full load SO2 levels with a Ca/S mole ratio of approximately 3 ranged from 1250 to 1330. The average was 1287 and the standard deviation 40. There were 3 tests each lasting between 2 and 3 hours.

Based on average figures the reduction in SO2 level was 658 ppm or 32% with a Ca/S mole ratio of 3 using granular limestone which is less expensive than the limestone powder used for the subsequent series of tests. The % by weight of sulphur in the coal was 2.6. In general, the % reduction would tend to be higher with higher sulphur coal.

6.2.2 November 1984 Tests

On November 23 unit no 2 ran without limestone with an SO2 level of 2450 parts per million. Following the introduction of limestone on November 23, and after reaching equilibrium, at a Ca/S ratio of 3.21, the SO2 concentration was reduced to 1136 part per million at a Ca/S ratio of 3.21. This represents a reduction of 1314 ppm or 53.6% during that day. The sulphur level in the coal was 2.93% by weight.

On November 27 number 1 boiler was tested without limestone

and the SO2 concentration was 2087 ppm.

During one test on November 28 with limestone injection and a Ca/S mole ratio of 2.78, the concentration of SO2 was 1169 ppm. During a second test on the same day with a Ca/S mole ratio of 2.93, the concentration was 1047 ppm. The lower concentration for Nov 28 was 1040 ppm less than the supplementary baseline level of 2087 ppm using the same coal on Nov 27. This is a 50% reduction.

On Nov 28 the level of sulphur in the coal was in the 2.7% to 2.9% range and the Ca/S ratio was between 2.78 and 2.93.

6.2.3 The December 1985 Tests

The sulphur level in the coal proved to be higher than the analysis available at the time of these tests indicated leading to a lower than desired Ca/S ratio. As well, mainly because of unburned carbon, the boiler efficiency proved to be lower. As a result, the Ca/S ratios were lower than intended.

On Dec 2 before limestone addition, the SO2 concentration was 1088 ppm. With a Ca/S ratio of 1.23 it was reduced to 630 ppm and with a Ca/S ratio of 2.61 to 499, a reduction of 42%. The sulphur level in the coal was approximately 2.37%.

On Dec 3 without limestone the ppm of SO2 was 1167, reducing to 881 with a Ca/S ratio of 1.44 and to 711 with a Ca/S ratio of 2.03. The reduction was 39%.

6.3 COMPARISONS OF KEY TEST RESULTS

Graphical comparisons of the test results are shown in Figure 17 to 20 inclusive. Details of the panel readings and emission results are given in the Appendix.

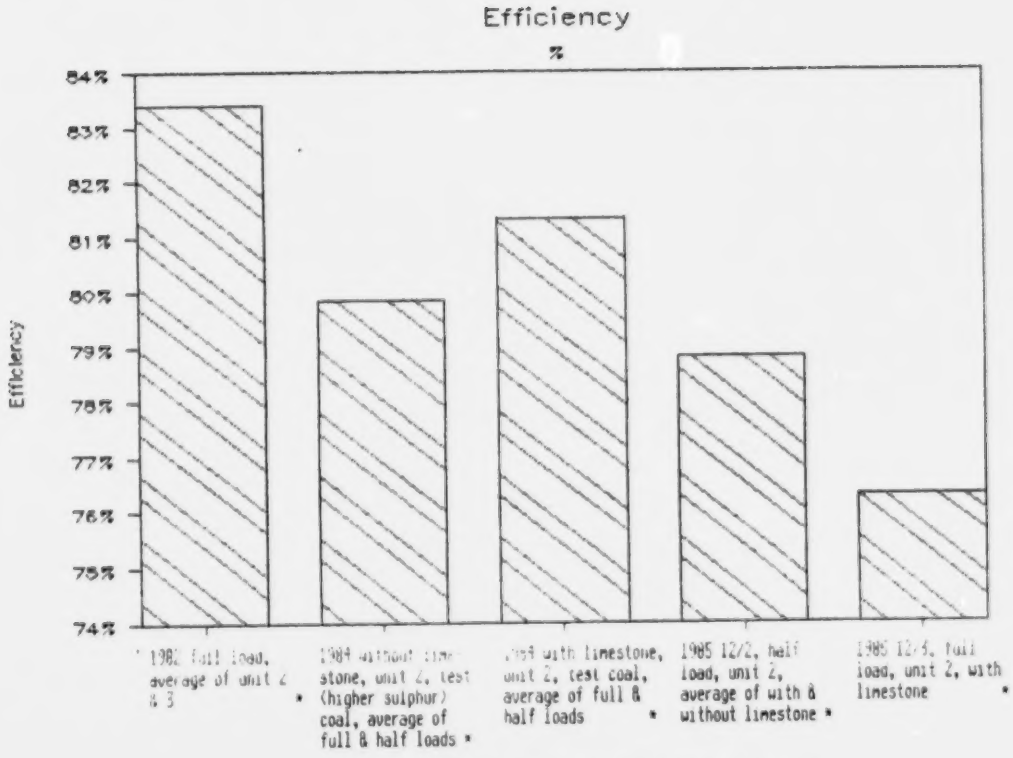

Efficiency
%
84%
83%
82%
81%
80%
79%
78%
77%
76%
75%
74%
Efficiency
1982 full load, average of unit 2 & 3 *
1984 without limestone, unit 2, test (higher sulphur) coal, average of full & half loads *
1984 with limestone, unit 2, test coal, average of full & half loads *
1985 12/2, half load, unit 2, average of with & without limestone *
1985 12/3, full load, unit 2, with limestone *

Figure 17: Boiler efficiencies for various tests & conditions

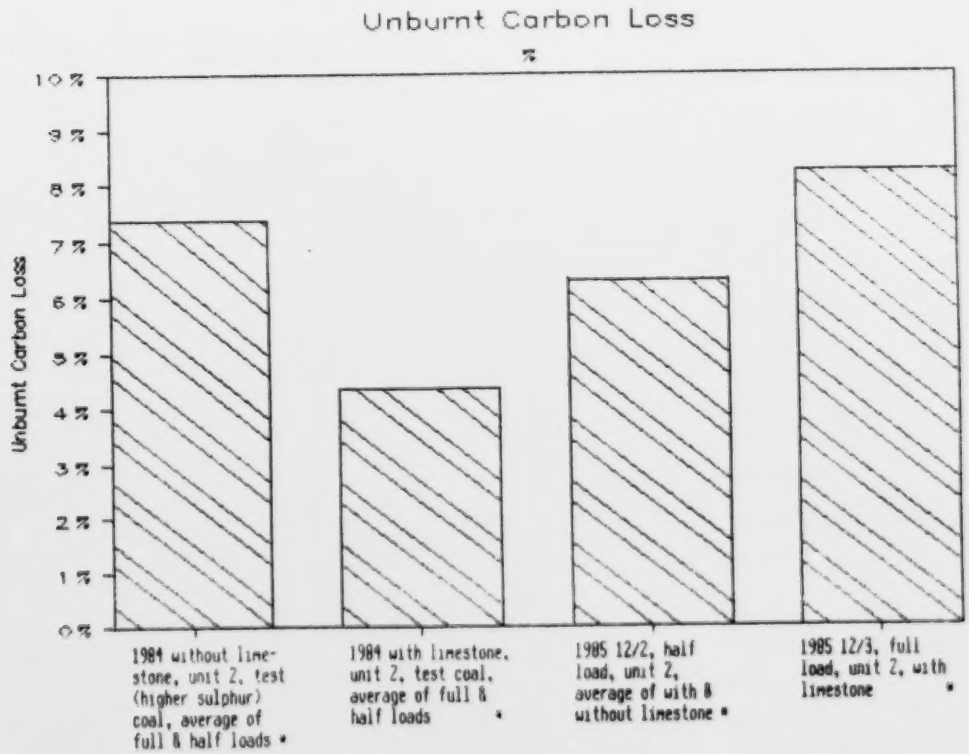


Figure 18: Unburnt carbon losses for various tests & conditions

* Tests with different conditions were averaged only if the results were similar.

Graph was drawn by fitting a curve to points calculated for the various tests. SO2 absorption was calculated by comparing emissions for comparable tests with & without limestone (eg. same burners, same load, PPMs' SO2 adjusted to represent the same % sulphur in the fuel with limestone).

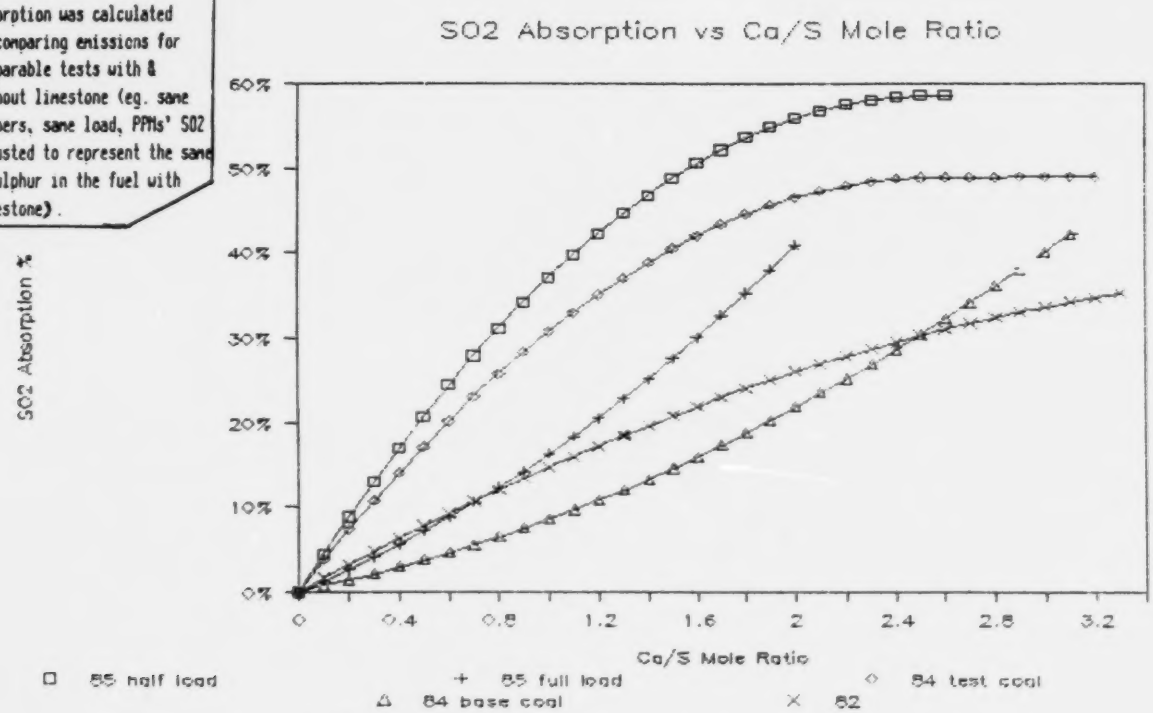


Figure 19: % SO2 Absorption for various tests

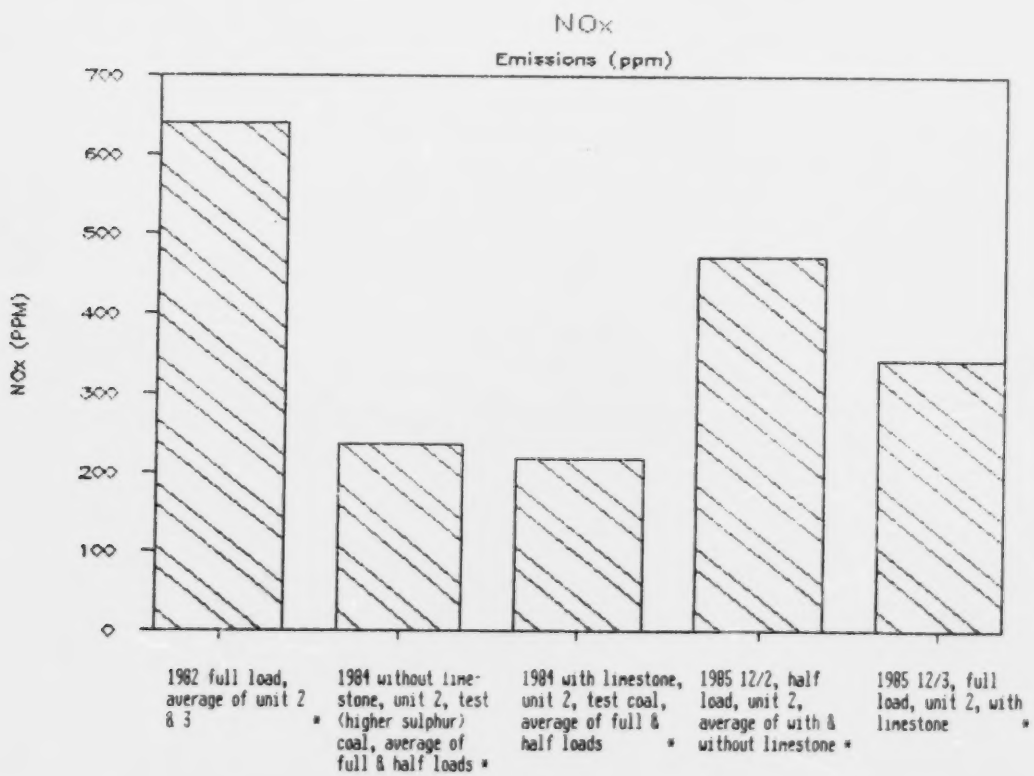

NOx
Emissions (ppm)
NOx (PPM)
700
600
500
400
300
200
100
0
1982 full load, average of unit 2 & 3 *
1984 without limestone, unit 2, test (higher sulphur) coal, average of full & half loads *
1984 with limestone, unit 2, test coal, average of full & half loads *
1985 12/2, half load, unit 2, average of with & without limestone *
1985 12/3, full load, unit 2, with limestone *

Figure 20: NOx for various tests

* Tests with different conditions were averaged only if the results were similar

6.4 TEST RESULTS

Table 1 Coal Analysis - Various Tests

	COAL % BY WT.							HHV	
	C	H	S	N	O	Ash	Water	BTU/lb	KJ/kg
1982 Baseline Tests	75.2%	4.8%	2.6%	1.4%	6.2%	8.4%	1.5%	14303	33266
1984 Without Limestone (Av)	68.6%	4.9%	3.2%	1.3%	12.4%	7.2%	2.3%	13446	31274
1984 With Limestone (Av)	70.2%	5.0%	2.8%	1.4%	11.1%	6.6%	2.9%	13451	31286
1985	72.3%	4.7%	2.4%	1.5%	6.8%	9.6%	2.8%	12749	29652

Table 2 March 1982 Baseline Test Results

The following table summarizes the baseline test results including boiler efficiency and mole ratio calculations for full load tests:

TEST RESULTS

DAY	HOUR	UNIT	LOAD MW	% O2 <***> (+++)	NOx <mg/MJ> (ppm)	SO2 <mg/MJ> (ppm)	CO ppm	BLR EFF% *	GAS TEMP ***	Ca/S MOLE *
26	845-1145	2	20	<3.6> (3.6)	<296> (480)	<1665> (1920)	18	85.6	211 C	0
26	1442—1628	2	10	<3.8> (3.8)	(300)	(2100)	**			0
27	930-1230	2	9	<4.0> (4.0)	(370)	(1930)	**			0
28	845-1145	3	20.6	<4.3> (6.0)	<360> (590)	<1620> (1970)	16	84.06	240 C	0
28	1545—1600	3	10.5	(6.2)	(420)	(1990)	26			0
29	800-1100	3	18.58	<4.74> (6.5)	<469> (720)	<1158> (1280)	1.5	82.47	260 C	3.25
29	1315—1615	3	8.5	(7.2)	(420)	(1200)	18			N.A.
30	900-1100	3	19.68	<4.51> (6.1)	<429> (660)	<1129> (1250)	1.7	82.77	256 C	3.13
30	1405—1550	3	19.96	<4.54> (6.3)	<459> (750)	<1131> (1330)	1.1	82.19	269 C	2.72

* The methods of calculating boiler efficiency and Ca/S ratio are in Appendix I.
** CO fluctuated too much to take proper average readings.
*** Sampling point: Where the flue gas exits the air heater.
NOx, SO2 and CO readings are corrected to 3% oxygen.
+++ Sampling point: Duct from the test boiler, just before the settling chamber.
Note: From March 26 to 27, the tests were done on unit 2.
After and including the 28th, unit 3 was used.
Test from the 29th through the 30th, involved limestone.

Table 3

Nov./84 Performance Tests without Limestone

	TEST	1	3	4	6	10
	DATE	Nov23	Nov27	Nov24	Nov26	Nov27
TIME	Start	11.3	10	16.3	12	15
	End	-16	-15	-20.3	-15.3	-16.3
	UNIT	2	1	2	2	1
	COAL	Test	Test	Test	Base	Test
Ca/S MOLE RATIO		0	0	0	0	0
COMBINED FUEL EFFICIENCY (%)		79.5	85.3	80.2	80.4	85.1
*ppm of SO2		2453	2087	2585	1117	1807
% Ash to Cyclone & Carryover		85	85	85	85	85
+% Carbon in Bottom Ash		10	2.1	20.2	11	1.38
+% CARBON IN CYCLONE ASH		51	20	60	55	14.25
Unburned C in Ash Loss (%)		6.37	1.02	8.36	4.6	.56
AH Outlet Temp. (C)		251.72	234.45	191.6	248.7	191.75
% O2 by Vol		4.53	4.6	5.54	5.32	8.11
Blr Output (MW)		18	17.64	11	17.18	10.02
H2 & H2O Loss (%)		4.4	4.69	4.21	4.57	5.3
Dry Gas Loss (%)		8.92	8.19	6.46	9.67	8.26
Oil Flowrate (L/hr)		90.83	336.1	44.44	93.3	363
Oil (% of Total Energy Input)		4.3	17.43	3.47	4.68	33.06
Limestone Feedrate (kg/hr)		0	0	0	0	0
Coal Feedrate (kg/hr)		2471	1903	1539	2217	911
KJ/kg Coal		31562.	32311.	30985.	33097.	31169.
COAL ANALYSIS	Carbon	71.06	73	66.16	77.76	69.01
	Hydrogen	5.02	5.15	4.79	5.58	5.1
	Nitrogen	1.26	1.23	1.35	1.41	1.42
	Oxygen	9.78	10.42	15.02	7.27	11.69
	Sulphur	3.44	2.75	3.02	1.55	2.9
	Ash	7.66	5.66	6.77	5.05	5.47
	Moisture	1.79	1.8	2.88	1.38	4.41

* Corrected to 3 % oxygen

Table 4

Nov./84 Performance Tests with Limestone Added

	TEST	2	5	7	8	9	11	12
	DATE	Nov23	Nov25	Nov26	Nov26	Nov26	Nov28	Nov28
	TIME Start	20.45	11	15.3	17	17.45	11	12
	End	-24	-16	-17	-17.45	-18.15	-12	-14.15
	COAL	Test	Test	Base	Base	Base	Test	Test
I								
	Ca/S MOLE RATIO	3.21	2.74	3.05	1.8	3.36	2.78	2.93
	COMBINED FUEL EFFICIENCY%	80.8	81	79.6	82.1	79.4	82.3	81.3
*	SO2 Absorption %	45.6	51	39.5	19.5	49.3	45.3	49.4
	PPM of SO2	1136	1133	658	853	570	1069	1047
	Calcium efficiency	.14189	.18594	.12945	.10831	.14673	.16299	.16875
I								
	%Ash to Cyclone+Carryover	85	85	85	85	85	85	85
+	% Carbon in Bottom Ash	.88	8.47	2.66	2.26	2.26	.24	.27
+	% CARBON IN CYCLONE ASH	10.6	19.88	32.55	27	27	13	13.93
	Unburned C in Ash Loss %	3.34	6.78	6.77	3.75	5.92	3.32	3.95
I								
	AH Outlet Temp. (C)	262.8	200.6	243.6	255.6	254.75	245.3	255.4
	% O2 by Vol	5.3	5.4	5	4.9	5.63	5.175	4.85
	Blr Output (MW)	17.5	10.7	16.9	17.1	16.57	16.4	16.3
	H2 & H2O Loss (%)	4.76	4.19	4.22	4.17	4.3	4.41	4.76
	Dry Gas Loss (%)	10.29	7.26	8.66	9.2	9.61	9.13	9.16
I								
	Oil Flowrate (L/hr)	94.5	44.1	94.5	94.5	93.3	90	90
	Oil (% Total Energy Input)	4.71	3.59	4.78	4.87	4.81	4.86	4.84
	Limestone Feedrate (kg/hr)	749.3	373.5	345.7	193	383.6	541	617.7
	KJ/kg Limestone	-591.3	-388.0	-661.9	-757.9	-578.3	-503.5	-477.1
	% CaCO3 in limestone	93.44	93.27	95.37	94.96	94.96	95.2	95.31
	Coal Feedrate (kg/hr)	2363	1492	2255	2181	2191	2147	2204
	KJ/kg Coal	31448.	30748.	32294.	32726.	32660	31778.	31169.
I								
	COAL ANALYSIS Carbon	71.5	70.12	74.16	74.38	75.12	70.31	69.01
	Hydrogen	5.32	4.76	4.89	4.92	5.09	4.97	5.1
	Nitrogen	1.22	1.44	1.37	1.59	1.45	1.4	1.42
	Oxygen	9.75	10.48	10.46	10.26	9.39	12.35	11.69
	Sulphur	2.93	2.71	1.51	1.47	1.56	2.74	2.9
	Ash	7.01	8	5.37	5.77	5.79	5.89	5.47
	Moisture	2.2	2.48	2.26	1.61	1.61	2.34	4.41

* Based on reduction in SO2 emissions, as measured by Environment Canada, from a comparable test with no limestone addition. Emissions with no limestone are adjusted by the ratio- % sulhpur with/without limestone. This ensures a similar % coal sulphur the for SO2 absorption calculation.

+ Includes only the carbon due to the coal or oil and not the carbon resulting from the limestone (organic carbon).

Gagetown December 1985 Tests SUMMARY TABLE 5 (metric units)

DATE Dec	TIME	LOAD (MW)	LIME-STONE kg/hr	TEMPERATURE Air Heater AIR IN (C)	TEMPERATURE Air Heater GAS OUT (C)	* % C IN ASH	% O2 (wet)	OIL FLOW (L/hr)	POLLUTION REDUCTION % SO2	POLLUTION REDUCTION % NOx
2	1130-1230	10.5	0	30.3	207.0	38.54%	6.9	100.0	0.00%	4.92%
2	1400-1545	10.0	139.7	30.3	221.3	38.54%	7.8	100.0	42.07%	5.64%
2	1615-1800	10.4	312.1	32.7	229.0	38.54%	7.5	100.0	58.74%	5.93%
3	1400-1500	15.75	0	21.5	244.5	48.31%	3.0	100.0	0.00%	23.20%
3	1630-1830	15.4	258.3	19.0	254.0	42.10%	4.3	100.0	24.50%	32.29%
3	1845-2030	15.1	361.2	20.0	263.0	42.10%	4.1	100.0	39.02%	38.16%

(British units)

DATE Dec	TIME	LOAD MBTU per hr	LIME-STONE lb/hr	TEMPERATURE Air Heater AIR IN (F)	TEMPERATURE Air Heater GAS OUT (F)	* % C IN ASH	% O2 (wet)	OIL FLOW lb/hr	POLLUTION REDUCTION % SO2	POLLUTION REDUCTION % NOx
2	1130-1230	35.8	0	86.6	404.6	38.54%	6.9	186.9	0.00%	4.92%
2	1400-1545	34.1	308.08	86.6	430.4	38.54%	7.8	186.9	42.07%	5.64%
2	1615-1800	35.5	688.04	90.8	444.2	38.54%	7.5	186.9	58.74%	5.93%
3	1400-1500	53.8	0	70.7	472.1	48.31%	3.0	186.9	0.00%	23.20%
3	1630-1830	52.5	569.41	66.2	489.2	42.10%	4.3	186.9	24.50%	32.29%
3	1845-2030	51.6	796.37	68.0	505.4	42.10%	4.1	186.9	39.02%	38.16%

SUMMARY TABLE 6 (metric units)

DATE Dec	TIME	LOAD (MW)	FEEDRATE Lime-stone (kg/hr)	FEEDRATE Oil L/hr	FEEDRATE Coal (kg/hr)	Ca/S Mole Ratio	SO2 Reduction	Efficiency	* % C IN ASH	Unburnt Carbon Loss %
2	1130-1230	10.5	0	100.0	1483.4	0.00	0.00%	79.00%	38.54%	6.29%
2	1400-1545	10.0	139.7	100.0	1439.4	1.19	42.07%	77.36%	38.54%	6.27%
2	1615-1800	10.4	312.1	100.0	1514.2	2.51	58.74%	80.07%	38.54%	6.32%
3	1400-1500	15.75	0	100.0	2393.4	0.00	0.00%	77.07%	48.31%	9.67%
3	1630-1830	15.4	258.3	100.0	2319.5	1.37	24.50%	75.77%	42.10%	7.53%
3	1845-2030	15.1	361.2	100.0	2294.3	1.93	39.02%	76.02%	42.10%	7.53%

DATE Dec	TIME	LOAD MBTU per hr	FEEDRATE Lime-stone	FEEDRATE Oil lb/hr	FEEDRATE Coal	Ca/S Mole Ratio	SO2 Reduction	Efficiency	* % C IN ASH	Unburnt Carbon Loss %
2	1130-1230	35.8	0	186.9	3270.2	0	0.00%	79.00%	38.54%	6.29%
2	1400-1545	34.1	308.08	186.9	3173.3	1.189	42.07%	77.36%	38.54%	6.27%
2	1615-1800	35.5	688.04	186.9	3338.2	2.508	58.74%	80.07%	38.54%	6.32%
3	1400-1500	53.8	0	186.9	5276.4	0	0.00%	77.07%	48.31%	9.67%
3	1630-1830	52.5	569.41	186.9	5113.6	1.371	24.50%	75.77%	42.10%	7.53%
3	1845-2030	51.6	796.37	186.9	5057.9	1.933	39.02%	76.02%	42.10%	7.53%

* As a percentage of the ash from the coal only (not limestone)

Coal Analysis as req. by wt.: Carbon 72.34%, Hydrogen 4.7, Sulphur 2.37, Nitrogen 1.45%, Ash 9.59, Oxygen 6.79, Water 2.76. HHV = 12749 BTU/lb.

7 CONCLUSIONS

Because the unburned carbon loss is excessive, the boiler efficiency is lower than contract specifications, the contract specifications are not met in terms of % carbon in the fly ash. Indications to date are that the SO_2 reduction requirements can be met but there is doubt about NOx. Efforts so far to improve carbon carryover have impaired NOx reduction capability to the point where contract specifications are not met. It may be possible to reduce carbon carryover to an acceptable level while achieving a significant reduction in NOx emissions, but significant burner modifications will be required.

8 OPERATING PROBLEMS AND RECOMMENDATIONS

Further stabilization of combustion and substantial reduction in carbon carryover are essential. While the increase in cross sectional area of the coal gun and the addition of swirl vanes at the coal gun outlet proposed by Steinmueller in Spring 1985 were incorporated prior to the 1985 tests, neither improved stability nor reduced carbon carryover was achieved. When the tertiary air baffles were removed flame stability improved. With the the tertiary air baffles in place, the air jets appeared to distort the vortex which is supposed to induce a flow of hot gas to the burner tip. Without the baffles some of the tertiary air appears to bypass the flame so there may be a case for baffles at a less acute angle.

Both the instability and the escessive carbon carryover are likely due in part to lack of uniformity in flow of the primary air/coal stream in to the furnace. Proper residence time, temperature and mixing in the flame appear to be lacking. Designing a low NOx burner may involve a compromise but in this case stable operation with complete combustion must be the priority.

If the burner can be made satisfactory to the operators and the carbon carry over reduced to an acceptable level the facility will be useful for NOx/SOx reduction experiments.

For evaluation of changes made during the summer of 1986, a TV camera, improved observation ports, a continuous CO monitor and arrangements for rapid determination of carbon carryover levels would help.

The limestone system valves should be automated and a second rotary valve should be installed at the impact plate outlet.

9 APPENDIX

Contents in Order that They Appear:

Limestone, Panel and Emission Data for 1982, 84 and 85 Tests

Schematics of Steinmuller Burner Flame

Method of Calculating Limestone Feedrate given the Ca/S Mole Ratio

Theory of Operation of Limestone Feedrate, Impact Plate Meter

Specication for Low NOx/SOx Burner Contract

Modified Steinmuller Burner used for 1985 Tests

! GAGETOWN 1982 TESTS !

Table A.1

SIEVE ANALYSIS LIME DUST

May 28, 1982

Size	Wt %
+100 mesh	2.7
-100+200 mesh	4.7
-200+230 mesh	3.1
-230+270 mesh	7.3
-270+325 mesh	3.2
- 325 ' mesh	79.1
	100.1

30 Tonnes/truck

Table A.2

MASS EMISSION DATA
FOR
CFB GAGETOWN (March 1982)

Date	Unit No.	Test Times	Load	Limestone Injection	Emission Rates (#/hr.)	
					SO_2	No_x (as NO_2)
March 25	2	0850-1150	Full	No	259.	54.1
	2	1442-1628	Full	No	246.	48.9
March 26	2	0845-1145	Full	No	308.	54.8
	2	1415-1715	½	No	172.	17.5
March 27	2	0930-1230	½	No	134.	18.7
	2	—	½	No	—	—
March 28	3	0845-1145	Full	No	327.	70.1
	3	1545-1600	½	No	—	—
March 29	3	0800-1100	Full	Yes	207.	83.9
	3	1315-1615	½	Yes	99.2	24.8
March 30	3	0900-1100	Full	Yes	213.	81.0
	3	1405-1550	Full	Yes	218.	88.4
March 31	3	1115-1304	½	Yes	103.	30.6
	3	1337-1527	½	Yes	88.0	23.9

DATA FROM CFB GATOWN : GAGETOWN 1984 TESTS !

Table A.3

NO 2 GENERATOR
DIFFERENCE BETWEEN % OXYGEN ON CHART AND DRY BASIS ANALYSERS AT AIR PREHEATER OUTLET = 1.25%. DUE IN PART TO THE FACT THAT THE BAILEY ANALYSERS MEASURES ON A WET BASIS, IN PART TO INFILTRATION OR AIR PREHEAT LEAKAGE AND POSSIBLY IN PART TO ERROR IN CALIBRATION OF BAILEY ANALYSER. THE DRY BASIS READINGS WERE HIGHER

TWO DRY BASIS ANALYSERS WERE USED AT THE AIR PREHEATER OUTLET, ONE PROVIDED BY ENVIRONMENT CANADA AND THE OTHER BY G A ROBB ASSOCIATES - SAME READING FOR BOTH. PROBES WERE TRAVERESED BUT NO SIGNIFICANT DIFFERENCE WAS FOUND AMONG POINTS ACROSS DUCT.

NO 2 GENERATOR
G A ROBB ASSOCIATES USED TWO THERMOCOUPLE ELECTRONIC THERMOMETERS TO MEASURE GAS TEMPERATURE AT AIR HEATER OUTLET. THESE BOTH READ 3 DEGREES C HIGHER THAN THE BAILEY RECORDER.

WED NOV 28
TEST AT ABOUT 16.4 MW WITH LIMESTONE INJECTION AND TEST COAL STARTED AT ABOUT 11 AM. FOR THE FIRST HOUR THE LIMESTONE FEEDRATE BASED ON INTEGRATOR READINGS AT THE BEGINNING AND END OF A HALF HOUR PERIOD (STOP WATCH USED) WAS 540.2 KG/HRI

LIMESTONE FEEDRATE INTEGRATOR READING AT 11.58 AM WHEN LIMESTONE FEEDRATE WAS INCREASED WAS 6070 AND STOP WATCH STARTED. WHEN STOP WATCH WAS STOPPED 2.116 HR LATER INTEGRATOR READING WAS 19140.

INTEGRATOR READING AT BEGINNING OF TEST		6070
" "END " " TEST		19140
DURATION OF TEST		2.116 HOURS
AVERAGE FEEKG/HOUR		617.6

NO 1 GENERATOR
THE BAILEY RECORDER ON THE PANNEL FOR GAS TEMP OUT OF AIR HEATER READ 1 DEG C LOW ACCORDING TO G A ROBB ASSOCIATES MEASUREMENTS.

THE BAILEY OXYGEN RECORDER READ ABOUT 0.2% LOWER THAN THE DRY BASIS ANALYSERS USED TO MEASURE OXYGEN AT THE AIR PREHEATER GAS OUTLET

DATA RECORDED DURING TEST WITH BOTH BURNERS AND AS NEAR FULL LOAD AS FEASIBLE WITH LIMESTONE INJECTION ON NOV 28 1984 MINIMUM OIL NO 2 GEN

Table A.4

Nov. 23, 84- Daytime: 100% load, Min. Oil, Unit 2, Test Coal

Time	Load (MW)	AIR HEATER (C) Air In	Air Out	Gas In	Gas Out	%O2- AH Gas Out Panel (wet)	Panel (dry)	Meter (dry)	OIL FLOW Litres/hr Bot.	Top
11:30	17.8	25	200	367	243	3.5	4.7	5.2	48	48
11:45	17.7	25	204	370	243	4.3	5.5		48	48
12:00	17.9	25	203	370	243	3.7	4.9	6	48	48
12:15	17.8		205	371	244	3.45	4.65		45	45
12:30	18.2		208	375	248	3.2	4.4	4.4	48	48
12:45	18		209.5	377	249	2.8	4		45	45
13:00	18		210	379	250	2.6	3.8	3.9	43	43
13:15	18.2		210	380.5	251	2.6	3.8		44	44
13:30	17.8		211	383	253	4	5.2	5.2	42	42
13:45	17.7		211	385	253	3	4.2	4.2		
14:00	18.5		211	387	253	3.4	4.6			
14:15	18		211	387	253	3.2	4.4		48	48
14:30	17.8	22.2222	212	387	253	3.9	5.1	4		
14:45	18		212	388	253	3.4	4.6			
15:00	18		213	390	255	3.1	4.3		45	45
15:15	18		214	390	258	4	5.2		45	45
15:30	18.5	17.7777	215	393	260.5	3	4.2	3.9	45	45
15:45	18.1		216	394	260	2.95	4.15	3.9	43	43

BRITISH

Time	Load MBTU hr	AIR HEATER (F) Air In	Air Out	Gas In	Gas Out	%O2- AH Gas Out Panel (wet)	Panel (dry)	Meter (dry)	OIL FLOW USGPM Bot.	Top
11:30	60.7	77	392	692.6	469.4	3.5	4.7	5.2	0.21	0.21
11:45	60.4	77	399.2	698	469.4	4.3	5.5		0.21	0.21
12:00	61.0	77	397.4	698	469.4	3.7	4.9	6	0.21	0.21
12:15	60.7		401	699.8	471.2	3.45	4.65		0.19	0.19
12:30	62.1		406.4	707	478.4	3.2	4.4	4.4	0.21	0.21
12:45	61.4		409.1	710.6	480.2	2.8	4		0.19	0.19
13:15	62.1		410	716.9	483.8	2.6	3.8	3.9	0.19	0.19
13:30	60.7		411.8	721.4	487.4	4	5.2		0.18	0.18
13:45	60.4		411.8	725	487.4	3	4.2	5.2		
14:00	63.1		411.8	728.6	487.4	3.4	4.6	4.2		
14:15	61.4		411.8	728.6	487.4	3.2	4.4		0.21	0.21
14:30	60.7	72	413.6	728.6	487.4	3.9	5.1			
14:45	61.4		413.6	730.4	487.4	3.4	4.6	4		
15:00	61.4		415.4	734	491	3.1	4.3		0.19	0.19
15:15	61.4		417.2	734	496.4	4	5.2		0.19	0.19
15:30	63.1	64	419	739.4	500.9	3	4.2		0.19	0.19
15:45	61.7		420.8	741.2	500	2.95	4.15	3.9	0.18	0.18

Table A.5

Nov. 23, 84- Evening: 100% Load, Min. oil, Unit 2, Test Coal, Limestone Addition

Time	Load (MW)	AIR HEATER (C) Air In	Air Out	Gas In	Gas Out	%O2- AH Gas Out Panel (wet)	Panel (dry)	Meter (dry)	OIL FLOW Litres/hr Bot.	Top
18:00	18.5		197	362	239	3.5	4.7	4.5	45	45
18:25	18.5	17.2222	203	370	246	3	4.2		48	48
19:30	18.5	21.1111	223	390	263	3	4.2		48	48
Test Start										
21:00	18	21.1111	225	390	264	3.4	4.6		48	48
21:15	18.1		227	393	265	3.4	4.6		48	48
21:30	18.3	24.4444	227	393	265	3.3	4.5	4.3		
21:45	17.5		225	389	263	4.1	5.3		48	48
22:00	17.4		222	387	261	5	6.2		48	48
22:22	17.4		221	385	261	4.2	5.4		45	45
22:30	17.2		222	389	262	4.7	5.9		48	48
22:50	17.3		222	389	263	3.8	5	4.8		
23:08	17.5		224	390	263	3.7	4.9			
23:26	17.5		225	390	263	4	5.2		48	48
23:34	17.5	25	225	390	263	4.2	5.4		48	48
23:45	17	25.1666	225	389	262	4.75	5.95		45	45
24:00	16.9	25.4444	225	389	261	4.7	5.9			

BRITISH

Time	Load MBTU hr	AIR HEATER (F) Air In	Air Out	Gas In	Gas Out	%O2- AH Gas Out Panel (wet)	Panel (dry)	Meter (dry)	OIL FLOW USGPM Bot.	T
18:00	63.1		386.6	683.6	462.2	3.5	4.7	4.5	0.19	0.19
18:25	63.1	63	397.4	698	474.8	3	4.2		0.21	0.21
19:30	63.1	70	433.4	734	505.4	3	4.2		0.21	0.21
Test Start										
21:00	61.4	70	437	734	507.2	3.4	4.6		0.21	0.21
21:15	61.7		440.6	739.4	509	3.4	4.6		0.21	0.21
21:30	62.4	76	440.6	739.4	509	3.3	4.5	4.3		
21:45	59.7		437	732.2	505.4	4.1	5.3		0.21	0.21
22:00	59.3		431.6	728.6	501.8	5	6.2		0.21	0.21
22:22	59.3		429.8	725	501.8	4.2	5.4		0.19	0.19
22:30	58.7		431.6	732.2	503.6	4.7	5.9		0.21	0.21
22:50	59.0		431.6	732.2	505.4	3.8	5	4.8		
23:08	59.7		435.2	734	505.4	3.7	4.9			
23:26	59.7		437	734	505.4	4	5.2		0.21	0.21
23:34	59.7	77	437	734	505.4	4.2	5.4		0.21	0.21
23:45	58.0	77.3	437	732.2	503.6	4.75	5.95		0.19	0.19
24:00	57.6	77.8	437	732.2	501.8	4.7	5.9			

Table A.6

Nov. 24, 84: Min. oil, Test Coal, Unit 2

Time	Load (MW)	AIR HEATER (C) Air In	Air Out	Gas In	Gas Out	%O2- AH Gas Out Panel (wet)	Panel (dry)	Meter (dry)	OIL FLOW Litres/hr Bot.	Top
Limestone addition, 100% Load:										
12:26	17		203	368	243	4.4	5.6		36	36
12:45	17.5		212	382	253	3.6	4.8		40	40
No Limestone, 50% Load:										
16:30	11.2		170	300.5	181	4.6	5.8		42	0
16:45	11		170	306	183	3.6	4.8		42	0
17:00	11.4		172	312	189	4.2	5.4		42	0
17:20	11.1		175	315	190	4.3	5.5		42	0
17:30	10.8		175	317	191	4.1	5.3		45	0
17:45	10.8	20.5555	176	319	190	4.9	6.1		42	0
18:07	11.2		177	320	191	4.6	5.8			0
18:15	11.2		177.5	319	191	4.5	5.7	5.7	42	0
18:30	11.3		176	320	191	4.4	5.6		42	0
18:45	10.8		179	322	193	4.4	5.6		45	0
19:00	10.7		179	321	193	4.2	5.4			0
19:15	10.9	19.4444	180	325	194	4.3	5.5	5.2	48	0
19:30	11		180	327	194	4.1	5.3		48	0
19:45	10.8		181	328	195					0
20:00	10.5		182	329	196	4.9	6.1		48	0
20:15	11	19.4444	183	330	196	4.2	5.4	5.2	45	0

BRITISH

Time	Load MBTU hr	AIR HEATER (F) Air In	Air Out	Gas In	Gas Out	%O2- AH Gas Out Panel (wet)	Panel (dry)	Meter (dry)	OIL FLOW USGPM Bot.	Top
Limestone addition, 100% Load:										
12:26	58.0		397.4	694.4	469.4	4.4	5.6		0.15	0.15
12:45	59.7		413.6	719.6	487.4	3.6	4.8		0.17	0.17
No Limestone, 50% Load:										
16:30	38.2		338	572.9	352.4	4.6	5.8		0.18	0
16:45	37.5		338	582.8	356	3.6	4.8		0.18	0
17:00	38.9		341.6	593.6	366.8	4.2	5.4		0.18	0
17:20	37.8		347	599	368.6	4.3	5.5		0.18	0
17:30	36.8		347	602.6	370.4	4.1	5.3		0.19	0
17:45	36.8	69	348.8	606.2	368.6	4.9	6.1		0.18	0
18:07	38.2		350.6	608	370.4	4.6	5.8			0
18:15	38.2		351.5	606.2	370.4	4.5	5.7	5.7	0.18	0
18:30	38.5		348.8	608	370.4	4.4	5.6		0.18	0
18:45	36.8		354.2	611.6	374	4.4	5.6		0.19	0
19:00	36.5		354.2	609.8	374	4.2	5.4			0
19:15	37.1	67	356	617	375.8	4.3	5.5	5.2	0.21	0
19:30	37.5		356	620.6	375.8	4.1	5.3		0.21	0
19:45	36.8		357.8	622.4	377.6					0
20:00	35.8		359.6	624.2	379.4	4.9	6.1		0.21	0
20:15	37.5	67	361.4	626	379.4	4.2	5.4	5.2	0.19	0

Table A.7

Sunday Nov.25, 84: 50% Load, Unit 2, Min.oil, Test Coal, Limestone addition

Time	Load	AIR HEATER (C)				%O2- AH Gas Out Panel		Meter	OIL FLOW Litres/hr	
	(MW)	Air In	Air Out	Gas In	Gas Out	(wet)	(dry)	(dry)	Bot.	Top
11:00	10.8		176.5	304	187	4.6	5.8		40	0
Limestone addition begins										
11:15	10.8		178	317	190				38	0
11:30	10.9	21.6666	180	325	193	5.1	6.3	6.2	42	0
11:45	10.8	22.2222	183	330	196	4.3	5.5		45	0
12:00	11	25.5555	185	330	199	4.2	5.4	5.2	45	0
12:15	10.7		185	331	199	4.5	5.7	5.6	45	0
12:35	10.6	25.5555	184	332	199	4.8	6		45	0
12:55	10.5		184	332	201	5.4	6.6		45	0
13:04	10.7		183	330	199	4.8	6		42	0
13:15	10.6		185	334	202	4	5.2	5	40	0
13:30	10.4	26.6666	186	331	202	3.8	5			0
13:45	10.6	26.1111	186	336	203	4.3	5.5		45	0
14:00	10.7		187	335	203	4.1	5.3	5.3	45	0
14:15	10.7		186	335	203	4.8	6			0
14:30	10.5	26.1111	186	336	203	4.2	5.4	5.3	45	0
14:45	10.7		187	339	203	4	5.2		45	0
15:00	10.5	26.6666	187	338	203	3.4	4.6		45	0
15:15	10.7	26.1111	186	339	203	3.05	4.25	4.3	45	0
15:30	10.8		187	339	204	3.5	4.7		48	0
15:45	10.6		185	340	206	3.3	4.5	4.5		0

BRITISH

Time	Load	AIR HEATER (F)				%O2- AH Gas Out Panel		Meter	OIL FLOW USGPM	
	MBTU hr	Air In	Air Out	Gas In	Gas Out	(wet)	(dry)	(dry)	Bot.	Top
11:00	36.8		349.7	579.2	368.6	4.6	5.8		0.17	0
Limestone addition begins										
11:15	36.8		352.4	602.6	374				0.16	0
11:30	37.1	71	356	617	379.4	5.1	6.3	6.2	0.18	0
11:45	36.8	72	361.4	626	384.8	4.3	5.5		0.19	0
12:00	37.5	78	365	626	390.2	4.2	5.4	5.2	0.19	0
12:15	36.5		365	627.8	390.2	4.5	5.7	5.6	0.19	0
12:35	36.1	78	363.2	629.6	390.2	4.8	6		0.19	0
12:55	35.8		363.2	629.6	393.8	5.4	6.6		0.19	0
13:04	36.5		361.4	626	390.2	4.8	6		0.18	0
13:15	36.1		365	633.2	395.6	4	5.2	5	0.17	0
13:30	35.4	80	366.8	627.8	395.6	3.8	5			0
13:45	36.1	79	366.8	636.8	397.4	4.3	5.5		0.19	0
14:00	36.5		368.6	635	397.4	4.1	5.3	5.3	0.19	0
14:15	36.6		366.8	635	397.4	4.8	6			0
14:30	35.8	79	366.8	636.8	397.4	4.2	5.4	5.3	0.19	0
14:45	36.5		368.6	642.2	397.4	4	5.2		0.19	0
15:00	35.8	80	368.6	640.4	397.4	3.4	4.6		0.19	0
15:15	36.5	79	366.8	642.2	397.4	3.05	4.25	4.3	0.19	0
15:30	36.8		368.6	642.2	399.2	3.5	4.7		0.21	0
15:45	36.1		365	644	402.8	3.3	4.5	4.5		

Table A.8

Nov. 26, 84: Unit 2, 100% Load, Low Sulpur Coal, Min. Oil

Time	Load (MW)	AIR HEATER (C) Air In	Air Out	Gas In	Gas Out	%O2- AH Gas Out Panel (wet)	Panel (dry)	Meter (dry)	OIL FLOW Litres/hr Bot.	Top
12:00	17.3	32.2222	198	368	243	4.2	5.4		42	42
12:15	17		198	369	243	4.9	6.1	6.1	42	42
12:30	17.6		201	373	247	3.9	5.1		45	45
12:45	17.1	25.5555	201	371	246	3.9	5.1	5.2	45	45
13:00	17		201	371	245	4	5.2			
13:22	16.8		201	371	246	4.2	5.4		45	45
13:30	17.5		202	373	249	3.65	4.85	4.5		
14:45	17.4		202	378	250	3.4	4.6			
15:00	17		206	378	251	5	6.2		50	50
Limestone Injection Started at 15:20										
15:30	16.5		192	353	233	4	5.2		Meter not	
15:50	16.5	28.0888	198	361	240	4.1	5.3	5.2	working	
16:05	17.5		200	368	243	2.6	3.8			
16:15	17		202	372	245	4.1	5.3			
16:30	16.5	27.2222	204	371	245	3.8	5	5.1		
16:45	17		205	372	248	4	5.2			
17:00	16.8		205	374	248	4.2	5.4			
17:15	17.5		220	390	262	4	5.2			
17:30	17.4		212	382	255	2.8	4	4.1		
17:45	16.7	28.8888	210	391	254	4.3	5.5			
18:00	16.5		210	392	255	4.5	5.7			

BRITISH

Time	Load MBTU hr	AIR HEATER (F) Air In	Air Out	Gas In	Gas Out	%O2- AH Gas Out Panel (wet)	Panel (dry)	Meter (dry)	OIL FLOW USGPM Bot.	Top
12:00	59.0	90	388.4	694.4	469.4	4.2	5.4		0.18	0.18
12:15	58.0		388.4	696.2	469.4	4.9	6.1	6.1	0.18	0.18
12:30	60.0		393.8	703.4	476.6	3.9	5.1		0.19	0.19
12:45	58.3	78	393.8	699.8	474.8	3.9	5.1	5.2	0.19	0.19
13:00	58.0		393.8	699.8	473	4	5.2			
13:22	57.3		393.8	699.8	474.8	4.2	5.4		0.19	0.19
13:30	59.7		395.6	703.4	480.2	3.65	4.85	4.5		
14:45	59.3		395.6	712.4	482	3.4	4.6			
15:00	58.0		402.8	712.4	483.8	5	6.2		0.22	0.22
Limestone Injection Started at 15:20										
15:30	56.3		377.6	667.4	451.4	4	5.2		Meter not	
15:50	56.3	84	388.4	681.8	464	4.1	5.3	5.2	working	
16:05	59.7		392	694.4	469.4	2.6	3.8			
16:15	58.0		395.6	701.6	473	4.1	5.3			
16:30	56.3	81	399.2	699.8	473	3.8	5	5.1		
16:45	58.0		401	701.6	478.4	4	5.2			
17:00	57.3		401	705.2	478.4	4.2	5.4			
17:15	59.7		428	734	503.6	4	5.2			
17:30	59.3		413.6	719.6	491	2.8	4	4.1		
17:45	56.9	84	410	735.8	489.2	4.3	5.5			
18:00	56.3		410	737.6	491	4.5	5.7			

Table A.9

Nov. 27, 84; Baseline Test: Unit 1, Test Coal, No Limestone Addition

Time	Load	AIR HEATER (C)				%O2- AH Gas Out			TOTAL OIL FLOW	
	(MW)	Air In	Air Out	Gas In	Gas Out	Panel (wet)	(dry)	Meter (dry)	Litres/hr	
8:30	18.7		Meter	350	226	3.1	3.3			
9:20	19		was	353	243	5.1	5.3			
Test Started at 9:30			not							
9:40	18.6		Working	349	235	5	5.2		365	
9:45	18.5			349	234	5	5.2		365	
10:00	18.7	31.6666		343	233	4.2	4.4	3.8	365	
10:15	19.2			340	228	2.85	3.05	2.9	365	
10:30	18.6			345	229	3.8	4		365	
10:45	19.7			350	231	3.6	3.8		365	
11:00	17.5			350	234	6.2	6.4		367	
11:15	17.2			350	232	5	5.2		367	
11:30	17	37.2222		354	235	5.1	5.3		367	
11:45	18.2	37.2222		351	234	4	4.2	4.1	367	
12:00	18.5			360	240	4.1	4.3			
12:15	17.7			357	239	4.7	4.9		372	
12:30	17			359	239	4.3	4.5		308	Min.
12:45	17.2			353	237	4	4.2		308	Oil
13:00	17.5	36.6666		353	236	4	4.2		308	Start
13:15	17.2			350	230	4.3	4.5		300	at
13:30	16.8	35.5555		357	239	5	5.2		308	12:30
13:45	16.5			350	233	5.3	5.5		308	
14:00	16.9			353	233	4.7	4.9		308	
14:15	16.6	28.3333		352	233	3.9	4.1	4	308	
50% Load, Baseline Test, Unit 1										
15:45	9.7			289	190	9.6	9.8		363	
15:51	9.5			290	191	8.9	9.1		363	
16:00	10.3	29.4444		289	192	9	9.2		357	
16:15	10.2	34.4444		290	195	3.5	3.7		357	
16:25	10.4	31.1111		289	195	8.53	8.73	9	375	

(BRITISH UNITS ON BACK)

Nov. 27, 84; Baseline Test BRITISH

Time	Load MBTU hr	AIR HEATER (F) Air In	Air Out	Gas In	Gas Out	%O2- AH Gas Out Panel (wet)	Panel (dry)	Meter (dry)	TOTAL OIL FLOW USGPM	
8:30	63.8	Meter		662	438.8	3.1	3.3			
9:20	64.8	was		667.4	469.4	5.1	5.3			
Test Started at 9:30		not								
9:40	63.4	Working		660.2	455	5	5.2		1.60	
9:45	63.1			660.2	453.2	5	5.2		1.60	
10:00	63.8	89		649.4	451.4	4.2	4.4	3.8	1.60	
10:15	65.5			644	442.4	2.85	3.05	2.9	1.60	
10:30	63.4			653	444.2	3.8	4		1.60	
10:45	67.2			662	447.8	3.6	3.8		1.60	
11:00	59.7			662	453.2	6.2	6.4		1.61	
11:15	58.7			662	449.6	5	5.2		1.61	
11:30	58.0	99		669.2	455	5.1	5.3		1.61	
11:45	62.1	99		663.8	453.2	4	4.2	4.1	1.61	
12:00	63.1			680	464	4.1	4.3			
12:15	60.4			674.6	462.2	4.7	4.9		1.63	
12:30	58.0			678.2	462.2	4.3	4.5		1.35	Min.
12:45	58.7			667.4	458.6	4	4.2		1.35	Oil
13:00	59.7	98		667.4	456.8	4	4.2		1.35	Start
13:15	58.7			676.4	460.4	4.3	4.5		1.35	at
13:30	57.3	96		676.4	462.2	5	5.2		1.35	12:30
13:45	56.3			674.6	451.4	5.3	5.5		1.35	
14:00	57.6			662	451.4	4.7	4.9		1.35	
14:15	56.6	83		667.4	451.4	3.9	4.1	4	1.35	
50% Load, Baseline Test, Unit 1										
15:45	33.1			552.2	374	9.6	9.8		1.59	
15:51	32.4			554	375.8	8.9	9.1		1.59	
16:00	35.1	85		552.2	377.6	9	9.2		1.57	
16:15	34.8	94		554	383	3.5	3.7		1.57	
16:25	35.4	88		552.2	383	8.53	8.73	9	1.65	

Table A.10

DATA RECORDED DURING TEST WITH BOTH BURNERS AND AS NEAR FULL LOAD AS FEASIBLE WITH LIMESTONE INJECTION ON NOV 28 1984 MINIMUM OIL NO 2 GEN

Nov. 28, 84: 100% load, min. oil, Unit 2, Test Coal, limestone addition

Time	Load	AIR HEATER (C)				%O2- AH Gas Out			OIL FLOW Litres/hr	
	(MW)	Air In	Air Out	Gas In	Gas Out	Panel (wet)	Panel (dry)	Meter (dry)	Bot.	Top
7:00	16.5		198	343	233	2.6	3.8		45	45
7:15	16.3		188	345	227	4	5.2		45	45
7:30	16.2		190	350	229	4	5.2		45	45
7:50	16.4			360	234	3.4	4.6		45	45
11:00	16.7		198	367	242	4	5.2		45	45
11:15	16.5		200	370	244	3.6	4.8		45	45
11:30	16.4	21.6666	202	375	246	3.8	5	5	45	45
11:45	16.1		201	373	246	4.5	5.7		45	45
12:00	16.4	26.6666	203	379	248	4	5.2		45	45
12:15	16.2		205	379	250	4.2	5.4		45	45
12:30	16		205	380	252	4	5.2		45	45
12:45	15.7		208	380	252	4.2	5.4	5.5	45	45
13:00	16.5		210	389	255	3.2	4.4		45	45
13:22	17	28.3333	216	391	261	2.9	4.1		45	45
13:30	16.5		219	395	262	3.4	4.6		45	45
13:45	16.5		220	OffScale	264	3.5	4.7		45	45

BRITISH

Time	Load MBTU hr	AIR HEATER (F)				%O2- AH Gas Out			OIL FLOW USGPM	
		Air In	Air Out	Gas In	Gas Out	Panel (wet)	Panel (dry)	Meter (dry)	Bot.	Top
7:00	56.3		388.4	649.4	451.4	2.6	3.8		0.19	0.19
7:15	55.6		370.4	653	440.6	4	5.2		0.19	0.19
7:30	55.4		374	662	444.2	4	5.2		0.19	0.19
7:50	55.9		32	680	453.2	3.4	4.6		0.19	0.19
11:00	56.9		388.4	692.6	467.6	4	5.2		0.19	0.19
11:15	56.3		392	698	471.2	3.6	4.8		0.19	0.19
11:30	55.9	71	395.6	707	474.8	3.8	5		0.19	0.19
11:45	54.9		393.8	703.4	474.8	4.5	5.7		0.19	0.19
12:00	55.9	80	397.4	714.2	478.4	4	5.2		0.19	0.19
12:15	55.2		401	714.2	482	4.2	5.4		0.19	0.19
12:30	54.6		401	716	485.6	4	5.2		0.19	0.19
12:45	53.5		406.4	716	485.6	4.2	5.4		0.19	0.19
13:00	56.3		410	732.2	491	3.2	4.4		0.19	0.19
13:22	58.0	83	420.8	735.8	501.8	2.9	4.1		0.19	0.19
13:30	56.3		426.2	743	503.6	3.4	4.6		0.19	0.19
13:45	56.3		428	OffScale	507.2	3.5	4.7		0.19	0.19

Table A.11

SUMMARY of GAS CONCENTRATION DATA

Date	Unit	Load	Limestone	Concentration of Gases				
				SO2*	NOx*	CO*	THC*	O2+
Nov. 23	2	≈ 100	no	2450.	245.	68.	< 5	4.90
	2	≈ 100	yes	1136.	254.	54.	< 5	5.60
Nov. 27	1	≈ 100	no	2087.	567.	10.	< 5	4.97
Nov. 28	2	≈ 100	yes	1169.	212.	78.	< 5	5.62
	2	≈ 100	yes	1047.	211.	67.	< 5	5.49

* - ppm, dry basis - corrected to 3% O2
\+ - %, dry basis

ENVIRONMENT CANADA

1984 ENVIRONMENT CANADA DATA

NOV 84

Table A.12

COMPARISON of STANDARD REFERENCE METHOD & CONTINUOUS MONITORING GAS CONCENTRATIONS - SO2

SO2 Test No.	Date	Conditions	Concentration of SO2 (dry, ppm)	
			SRM*	CSM
1	Nov. 23	100%, no limestone	2117	2154
2	Nov. 23	100%, no limestone	2218	2190
3	Nov. 23	100% with limestone	1011	1019
4	Nov. 23	100% with limestone	996	1002

Table A.13

COMPARISON of STANDARD REFERENCE METHOD & CONTINUOUS MONITORING GAS CONCENTRATIONS - NOx

NOx Test No.	Date	Conditions	Concentration of NOx (dry, ppm)	
			SRM	CSM
1	Nov. 23	100% load	191	
2	Nov. 23	with	209	Average
3	Nov. 23	limestone	217	217 ppm
4	Nov. 23	injection	209	

Mean = 206.5

ENVIRONMENT CANADA

Table A.14

TABLE 4 - PARTICULATE STANDARD REFERENCE TESTING RESULTS

Date	Unit	Load (%)	Limestone	Run	Concentration (g/m3)+	Mass Flux kg/h
23	2	≈100	no	1	4.27	110.
				2	4.19	114.
	2	≈100	yes	3	10.21	284.
				4	10.30	283.
24	2	≈ 50	no	5	3.86	61.2
				6	3.84	59.9
25	2	≈ 50	yes	7	7.08	106.
				8	8.34	127.
26	2	≈100	no	9	4.02	106.
			yes	10	6.00	154.
27	1	≈100	no	11*	3.20	87.1
				12	3.68	95.6
				13	3.37	87.6

+ - dry basis at 25°C and 101.3 kPa.
* - Invalid Test

ENVIRONMENT CANADA

GAGETOWN 1985 TESTS

Table A.15

Dec. 2, 1985; Half Load

	Time	Load (MW)	AIR HEATER (C) Air In	Air Out	Gas In	Gas Out	%O2 Panel (wet)	OIL FLOW Litres/hr Bot.	Top
X	11:30	10.5	30	178	326	203	7.5	100	
X	12:00	10.5	30	180	333	208	6.8	100	
X	12:30	10.5	31	184	337	210	6.3	100	
	14:00	10	31	187	340	216	8.2	100	
	15:00	10	30	190	347	223	7.5	100	
	15:30	10	30	191	350	225	7.6	100	
	16:30	10.2	30	192	351	227	7.5	100	
	17:00	10.5	31	194	352	230	7.5	100	
	18:00	10.5	37	191	352	230	7.5	100	

BRITISH

	Time	Load MBTU hr	AIR HEATER (F) Air In	Air Out	Gas In	Gas Out	%O2 Panel (wet)	OIL FLOW USGPM Bot.	Top
X	11:30	35.83	86.0	352.4	618.8	397.4	7.5	0.44	0
X	12:00	35.83	86.0	356.0	631.4	406.4	6.8	0.44	0
X	12:30	35.83	87.8	363.2	638.6	410.0	6.3	0.44	0
	14:00	34.12	87.8	368.6	644.0	420.8	8.2	0.44	0
	15:00	34.12	86.0	374.0	656.6	433.4	7.5	0.44	0
	15:30	34.12	86.0	375.8	662.0	437.0	7.6	0.44	0
	16:30	34.81	86.0	377.6	663.8	440.6	7.5	0.44	0
	17:00	35.83	87.8	381.2	665.6	446.0	7.5	0.44	0
	18:00	35.83	98.6	375.8	665.6	446.0	7.5	0.44	0

X Test done without limestone addition.

Table A.16

Dec. 3,1985: Full Load

	Time	Load (MW)	AIR HEATER (C) Air In	Air Out	Gas In	Gas Out	%02 Panel (wet)	OIL FLOW Litres/hr Bot.	Top
X	14:00	16.0	23	200	358	240	3.5	50	50
X	15:00	15.5	20	205	363	249	2.5	50	50
	16:30	15.5	19	209	360	253	4.6	50	50
	17:00	15.5	19	206	368	254	4.0	50	50
	17:30	15.0	19	205	368	253	4.5	50	50
	18:00	15.5	19	208	373	256	4.0	50	50
	19:00	15.0	20	214	379	262	4.5	50	50
	19:37	15.0	20	213	376	260	4.5	50	50
	20:00	15.0	20	215	382	262	4.0	50	50
	20:30	15.5	20	220	392	268	3.5	50	50

BRITISH

	Time	Load MBTU hr	AIR HEATER (F) Air In	Air Out	Gas In	Gas Out	%02 Panel (wet)	OIL FLOW USGPM Bot.	Top
X	14:00	54.60	73.4	392.0	676.4	464.0	3.5	0.22	0.22
X	15:00	52.89	68.0	401.0	685.4	480.2	2.5	0.22	0.22
	16:30	52.89	66.2	408.2	680.0	487.4	4.6	0.22	0.22
	17:00	52.89	66.2	402.8	694.4	489.2	4.0	0.22	0.22
	17:30	51.19	66.2	401.0	694.4	487.4	4.5	0.22	0.22
	18:00	52.89	66.2	406.4	703.4	492.8	4	0.22	0.22
	19:00	51.19	68.0	417.2	714.2	503.6	4.5	0.22	0.22
	19:37	51.19	68.0	415.4	708.8	500.0	4.5	0.22	0.22
	20:00	51.19	68.0	419.0	719.6	503.6	4	0.22	0.22
	20:30	52.89	68.0	428.0	737.6	514.4	3.5	0.22	0.22

X Test done without limestone addition.

Table A.17
LIMESTONE FEEDRATES
Monday Dec. 2, 1985: Base Coal, Unit 2, Minimum Oil

Time		IMPACT PLATE				% of
		Totalizer	Feedrate	Feedrate for Entire Period		1200
Hr	Min.Sec	kg	kg/hr *	kg/hr	lb/hr	kg/hr
14	26	77.2				12
14	36	100.5	139.8			12
15	16	193.7	139.8			12
15	45	261.2	139.7			12
				139.7	308.1	
17	14	667.5				26
17	53	870.4	312.2			26
18	17	995.2	312.0			26
				312.1	688.0	

* Calculated by subtracting the immediately previous totalizer reading and time from the reading and time on the current line.

Table A.18
LIMESTONE FEEDRATES
Monday Dec. 3, 1985: Base Coal, Unit 2, Minimum Oil

Time		IMPACT PLATE				% of
		Totalizer	Feedrate	Feedrate for Entire Period		1200
Hr	Min.Sec	kg	kg/hr *	kg/hr	lb/hr	kg/hr
17	19	1800.0				21
17	40	1888.5	252.9			21
18	22	2071.2	261.0			21
				258.3	569.4	
18	51	2243.8				30
19	41	2548.6	365.8			30
20	0	2662.6	360.0			30
20	33	2857.9	355.1			30
				361.2	796.4	

* Calculated by subtracting the immediately previous totalizer reading and time from the reading and time on the current line.

Table A.19
% CARBON IN THE ASH RESULTING FROM COAL ONLY
Dec. 2, 1985 (No separate analyses were available with & without limestone)

Source of Ash	% Carbon with Carbonates Removed	% Carbon With Other Limestone Residue Removed	% of Total Ash from Source
Collection Chamber	44.74%	45.66%	5.00%
Cyclone Separator	27.48%	42.09%	85.00%
Furnace Bottom	2.64%	4.81%	10.00%
Overall % Coal Carbon in Coal Ash	25.86%	38.54%	100%

Table A.20
% CARBON IN THE ASH RESULTING FROM COAL ONLY
Dec. 3, 1985, 16:00 (Without Limestone Added)

Source of Ash	% Carbon with Carbonates Removed	% Carbon With Other Limestone Residue Removed	% of Total Ash from Source
Collection Chamber	22.12%	36.57%	5.00%
Cyclone Separator	54.58%	54.58%	85.00%
Furnace Bottom	0.48%	0.93%	10.00%
Overall % Coal Carbon in Coal Ash	47.55%	48.31%	100%

Dec. 3, 1985, 16:00 (With Limestone Added)

Source of Ash	% Carbon with Carbonates Removed	% Carbon With Other Limestone Residue Removed	% of Total Ash from Source
Collection Chamber	22.12%	36.57%	5.00%
Cyclone Separator	34.43%	47.27%	85.00%
Furnace Bottom	0.48%	0.93%	10.00%
Overall % Coal Carbon in Coal Ash	30.42%	42.10%	100%

Table A.21
AIR POLLUTION AS MEASURED BY ENVIRONMENT CANADA
Dec. 2, 1985

TIME	LIMESTONE FEEDRATE (kg/hr)	SO2 (PPM)	** Reduction %	NOx (PPM)	* Reduction %	CO (PPM)	O2 % by vol.
11:30 to 11:45	0	1036.		477.5	4.49%	123.4	8.32
11:45 to 12:00	0	1064.		475.1	4.96%	99.2	7.67
12:00 to 12:15	0	1086.		473.5	5.28%	96.5	7.66
12:15 to 12:30	0	1113.		475.1	4.96%	97.9	7.67
11:30 To 12:30	0	1088.		475.3	4.92%	104.2	7.83
14:00 to 14:15		662.0	39.17%	460.0	7.99%	137.9	8.59
14:15 to 14:30		638.0	41.38%	467.2	6.54%	95.0	7.62
14:30 to 14:45	139.80	659.5	39.40%	483.1	3.37%	109.9	8.5
14:45 to 15:00	139.80	613.1	43.67%	472.7	5.45%	110.4	8.56
15:00 to 15:15	139.80	608.6	44.08%	473.2	5.35%	108.6	8.31
15:15 to 15:30	139.66	601.3	44.75%	474.3	5.12%	108.2	8.26
14:00 To 15:30	139.75	630.4	42.07%	471.8	5.64%	111.7	8.31
16:30 to 16:45		411.6	62.18%	466.2	6.74%	91.5	7.45
16:45 to 17:00		464.4	57.33%	471.0	5.80%	101.0	7.97
17:00 to 17:15		457.1	57.99%	473.5	5.30%	118.4	8.54
17:15 to 17:30	312.15	457.7	57.94%	471.4	5.72%	122.6	8.56
17:30 to 17:45	312.15	448.3	58.80%	470.4	5.92%	133.8	8.75
17:45 to 18:00	312.00	454.9	58.19%	469.6	6.08%	115.7	8.19
16:30 To 18:00	312.10	449.0	58.74%	470.3	5.93%	113.8	8.24

* Based on NOx emmisions of 500 PPM without the low NOx/SOx burner determined during the 1982 tests and written into the contract.

** Based on typical SOx emissions without limestone taken just before limestone was added.

Note: The PPM have been adjusted to 3% oxygen in the flue gas.

Table A.22
AIR POLLUTION AS MEASURED BY ENVIRONMENT CANADA
Dec. 3, 1985

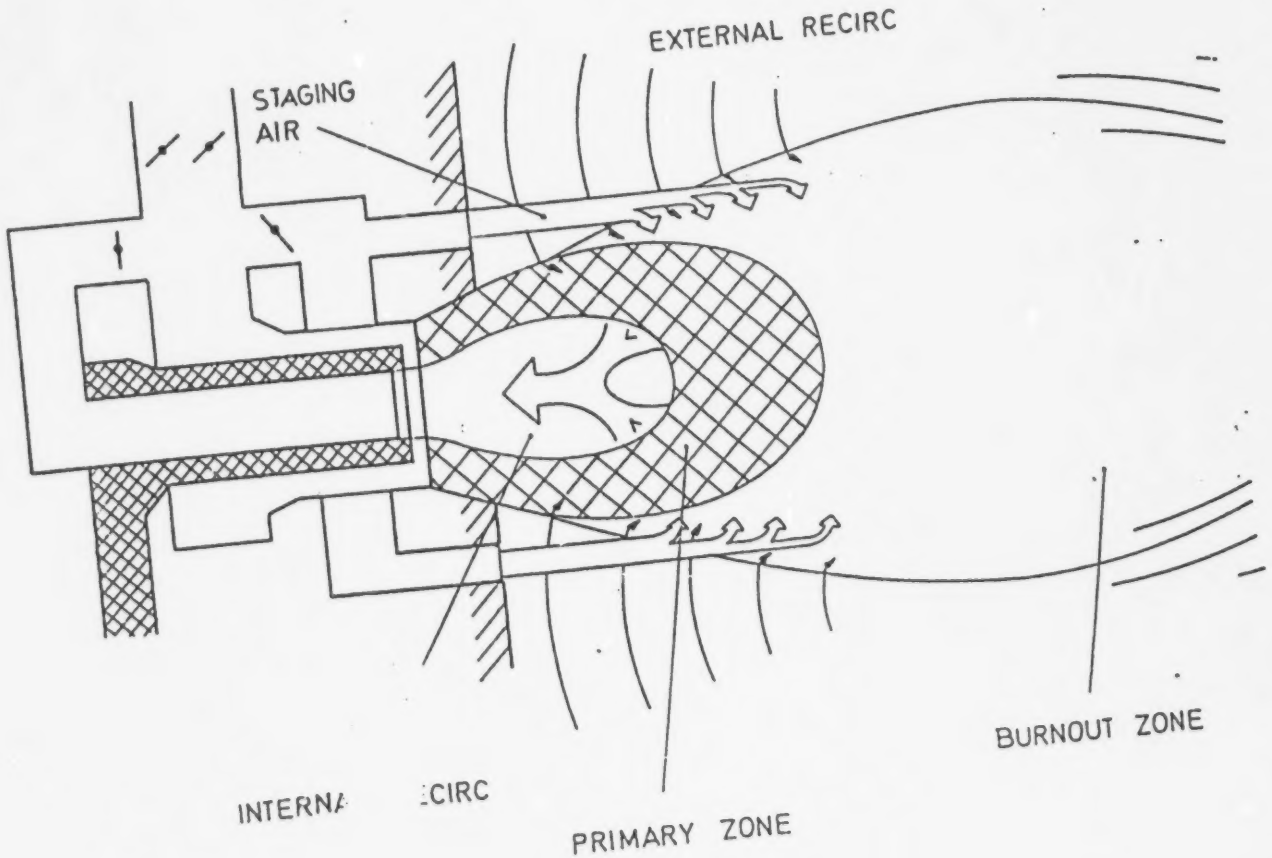
TIME	LIMESTONE FEEDRATE (kg/hr)	SO2 (PPM)	SO2 Reduction %	NOx (PPM)	NOx Reduction %	CO (PPM)	O2 % by vol.
14:00 to 14:15	0.00	1165.		379.4	24.12%	57.5	4.62
14:15 to 14:30	0.00	1162.		380	24.00%	61.1	4.76
14:30 to 14:45	0.00	1164.		397.8	20.42%	56.8	4.78
14:45 to 15:00	0.00	1176.		378.6	24.27%	49.2	3.92
14:00 To 15:00	0.00	1167.		383.9	23.20%	56.2	4.52
16:30 to 16:45		913.6	21.73%	350.2	29.96%	57.2	5.28
16:45 to 17:00		948.2	18.77%	345.5	30.88%	32.8	4.79
17:00 to 17:15		859.6	26.36%	352.3	29.53%	45.9	5.69
17:15 to 17:30	252.86	860.5	26.28%	324.6	35.06%	56.8	5.49
17:30 to 17:45	252.86	838.1	28.20%	317.7	36.46%	111.4	6.27
17:45 to 18:00	261.00	867.4	25.69%	340.8	31.84%	47.3	4.89
16:30 To 18:00	258.29	881.2	24.50%	338.5	32.29%	58.6	5.40
19:00 to 19:15	365.76	916.3	21.49%	283.0	43.39%	50.4	7.73
19:15 to 19:30	365.76	734.5	37.07%	299.6	40.06%	62.0	5.35
19:30 to 19:45	365.76	682.4	41.54%	296.1	40.77%	57.4	5.34
19:45 to 20:00	360.00	598.8	48.69%	318.9	36.21%	40.1	5.16
20:00 to 20:15	355.09	675.6	42.12%	336.1	32.77%	41.6	5.31
20:15 to 20:30	355.09	662.8	43.22%	321.2	35.75%	43.0	6.4
19:00 To 20:30	361.24	711.8	39.02%	309.2	38.16%	49.1	5.88

* Based on NOx emmisions of 500 PPM without the low NOx/SOx burner determined during the 1982 tests and written into the contract.

** Based on typical SOx emissions without limestone taken just before limestone was added.

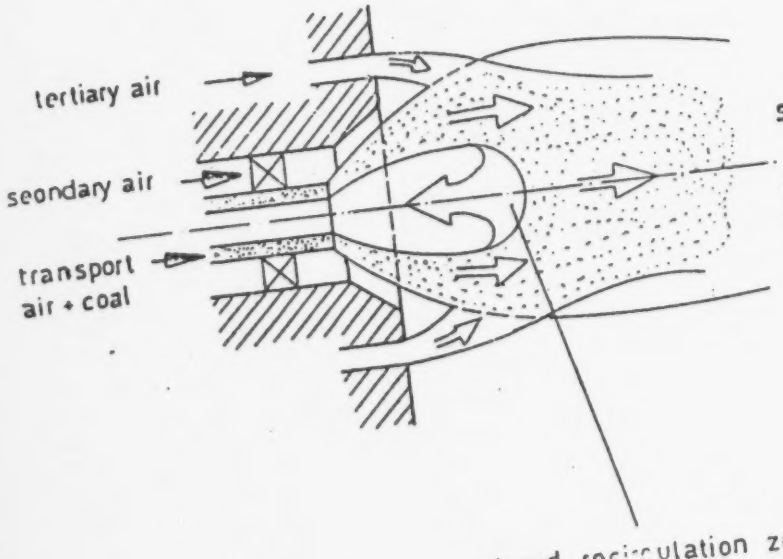
Note: The PPM have been adjusted to 3% oxygen in the flue gas.

SM - BURNER, SCHEMATIC OF FLOW AND MIXING REGIME

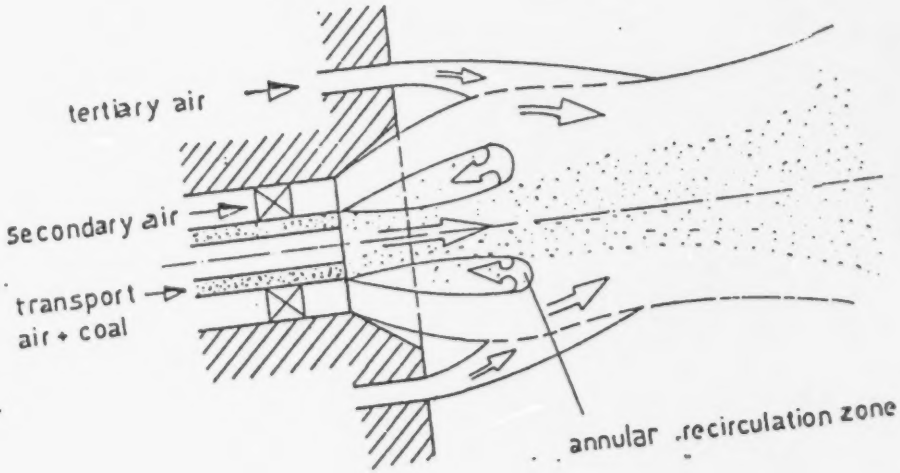


SM - BURNER, FLOWPATTERN DEPENDING ON SECONDARY AIR / TRANSPORT AIR ($S/_T$) RATIO

$\frac{S}{T}$ HIGH



$\frac{S}{T}$ LOW



STEINMÜLLER

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Method of Calculating Limestone Feedrate

The lbs of limestone per lb of coal is calculated assuming a desired calcium to sulphur in coal ratio and percentage of $CaCO_3$ in the limestone aswellas the % sulphur in the coal. The equation used for this calculation is as follows:

$$LC = \frac{CAS \times 100.073 \times S}{32.064 \times C3}$$

where

LC = Lbs limestone per lbs coal

CAS = desired calcium/ sulphur in the coal.

S = % sulphur by weight in coal

C3 = % $CaCO_3$ in limestone by weight

100.073 = the molecular weight of $CaCO_3$ or the lbs of $CaCO_3$ per mole of $CaCO_3$. It is also the lbs of $CaCO_3$ per mole of Ca in $CaCO_3$.

32.064 = the molecular weight of sulphur

The unit equation for the above is:

$$\frac{\#lime.}{\#coal} = \frac{\text{moles Ca/mole S} \times \#CaCO_3/\text{mole Ca} \times \#sulphur/\#coal}{\#sulphur/\text{mole sulphur} \times \#CaCO_3/\#limestone}$$

The lbs of coal per hour is then derived by dividing the boiler output by the boiler efficiency (about 82%) and multipling by the coal calorific value. Lbs of limestone consumed per hour can then be obtained by multipling the lbs of coal per hour by the lbs of limestone per lb of coal obtained above.

Limestone and Coal Required for the Fall, 84 NOx/SOx Tests

Calcium in Limestone/ Sulphur in Coal Ratio (CAS) = 2.5

% Sulphur by Weight in Coal (S) (wet basis)= 2.7

% $CaCO_3$ by Weight in Limestone = 90

$$\text{Lbs Limestone per Lb Coal (LC)} = \frac{2.5 \times 100.073 \times 2.7}{32.064 \times 90}$$

= 0.2341 (based on Sydney coal with 10 % moisture)

Hours of Operation at Full Load (20MW or 70 MBTU/hr)= 75

Hours of Operation at Half Load (10MW or 35 MBTU/hr)=

It is assumed that there will be 5 days of 15 hour test with limestone at full load.

Calorific Value of Coal (BTU/lb) = 12,885 (HHV wet basis)

$$\text{Lbs of Coal Required for Limestone Tests} = \frac{75 \times 20 \times 3412800}{12885}$$

=397,300 lbs (180,200 kg)

Lbs of Limestone Required = LC x Lbs of Coal Required

= 0.2341 x 397,300

= 93,008 lbs.

Adding 40 % as a safety factor the the minimum quantity of limestone that should be ordered is 130,000 lbs (59,000 kg).

Tests without Limestone

Hours of Operation at Full Load (20 MW) = 45 (3, 15 hr days)

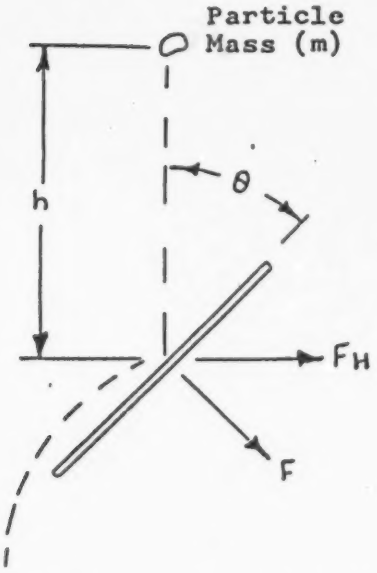
$$\text{Coal for tests without limestone} = \frac{45 \times 20 \times 3,412,800}{12,885.6}$$

= 238,368 lbs (wet basis)

Adding 40 % as a safety factor the the minimum quantity of coal for the tests with and without limestone should be is 900,000 lbs (408,200 kg or 408.2 metric tonnes).

THEORY OF OPERATION

The Sankyo Impact Line Flowmeter was designed to work on the principles of momentum and impact. If a particle of mass (m) is dropped from a height (h) on to a plate which is inclined (Θ) degrees from the vertical, it will hit the plate with a velocity v_1, be deflected, and bounce off with a velocity v_2. When the particle hits the plate, it will impart an impulse to the plate which is proportional to change in velocity of the particle.



Impulse imparted to plate = change of momentum of particle.

Impulse = Force x length of time applied = Ft

$$\text{Momentum} = m(v_1 - v_2)$$

$$Ft = m(v_1 - v_2)$$

$$Ft = \frac{w}{g}(v_1 - v_2)$$

Where $v_1 = f(h)$

$v_2 = f(h, \theta, u, e)$

u = coefficient of friction between plate & particle

e = coefficient of elasticity of particle

For a given set of conditions, h, Θ, u, and e will all be constants.

$Ft = Wk$ where F = force on the plate

$F = k\frac{w}{t}$ $\frac{w}{t}$ = flow rate of particles

k = constant = f(h, Θ, u, e)

The mechanism of the Sankyo Impact Line Flowmeter is designed to measure only the horizontal component (F_H) of the impact force (F).

$$F_H = F \cos \theta$$

$$F_H = k\frac{w}{t}\cos\theta$$

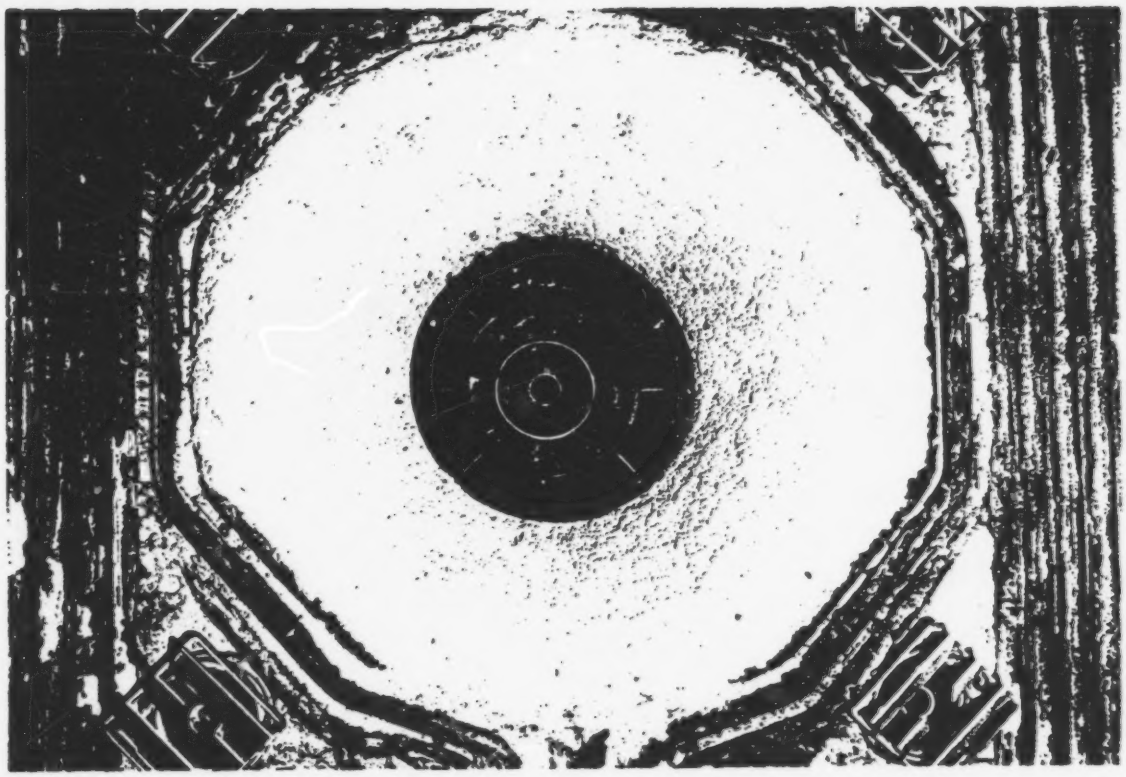
$$= k_1\frac{w}{t}$$

Or: The horizontal component of the impact force on the plate is directly proportional to the flow rate of material over the plate.

As shown in the theorectical model, the horizontal force acts against a compression spring, through a set of frictionless bearings, and is converted to a horizontal movement. Transients are smoothed out in a viscous damper and the movement is converted to an electrical signal in a linear voltage differential transformer.

Since: Force is proportional to flowrate,
Movement is proportional to force,
Voltage is proportional to movement.

Therefore: The voltage out of the differential transformer is directly proportional to the flowrate of material over the plate.



Modified Steinmuller Burner used for November 1985 Tests

APPENDIX "A"

SPECIFICATIONS

1. Performance Requirements

1.1 The retrofit burners and calcium injection system shall be a complete package compatible with the existing boiler, ancillaries and available space. Any additional equipment, material or systems must be specified and included in the overall cost.

1.2 The integrated burner and additive system to be developed and supplied shall be guaranteed to meet the following requirements:

a) Nitrogen oxide and suplhur dioxide levels shall be reduced by 50% or more without support firing at full load in Boiler #2 while burning the coal specified in Annex 1 with Havelock limestone injection. The limestone addition rate shall not exceed a Ca/S mol ratio of 2.5 to achieve the specified level of SO_x reduction. For purposes of this RFP the NO_x level is considered to be 500 ppm corrected to 3% oxygen and the SO_x level is considered to be 1900 ppm corrected to 3% oxygen. Thus, the NO_x target is 250 ppm corrected to 3% oxygen and the SO_x target is 950 ppm corrected to 3% oxygen. NO_x and SO_x levels will be determined by Environment Canada EPS methods, EPS-1-AP-77-3 and EPS-1-AP-74-3 respectively.

b) While operating at full load on coal only, with combustion air and calcium set to provide the guaranteed NO_x and SO_x levels, the boiler exit temperature shall not exceed 390°C with soot-blowing at consecutive four (4) hour intervals.

i) The flame length shall not exceed those in current operation; impingement of flame on boiler side, front or back walls is unacceptable.

ii) The fireside deposits in the boiler shall remain dry and be removable with the existing soot blowers; slagging or fouling of boiler surfaces must not occur.

iii) Combustible in flyash shall not exceed 7% by weight before the settling chamber collector.

iv) Combustion efficiency as determined by the ASME PTC-4.1-1964 heat loss method shall not be less than 82% at full load on coal only.